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(Supersedes IMR No. 644)

BALLISTIC EVALUATION OF 19-PERFORATION PROPELLANT IN THE 155-MM PROPELLING CHARGE, M203E1

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October 1979

US ARMY ARMAMENT RESEARCH AND DEVELOPMENT COMMAND
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ABERDEEN PROVING GROUND, MARYLAND

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dek/ Top-zone propelling charges for the Army 155-mm Howitzer were manufactured using 19-perforation, M30A1, granular propellant and tested against M203E1 Propelling Charges employing standard 7-perforation propellant. Velocities, chamber pressures, pressure wave levels ($-\Delta P_i$), and ignition delays were essentially equivalent for the two charges when fired at ambient temperatures or after cold conditioning (-51°C). Significant differences in performance, however, were exhibited by the two

charges when fired hot (+63°C). The mean $-\Delta P_i$ level for the 19-perforation charges hot was 41-percent lower than that for the 7-perforation, M203E1 firings, despite a 6-percent higher maximum chamber pressure for the 19-perforation charges.

TABLE OF CONTENTS

	Page
LIST OF ILLUSTRATIONS	5
LIST OF TABLES.	7
I. INTRODUCTION	9
II. TESTING.	11
III. RESULTS AND DISCUSSION	11
A. Nominal Performance Characteristics.	11
B. High-Temperature Firings	14
C. Low-Temperature Firings.	17
IV. CONCLUSIONS AND RECOMMENDATIONS.	20
ACKNOWLEDGMENTS.	21
REFERENCES	22
APPENDIX A. PROPELLANT DESCRIPTION SHEETS	23
APPENDIX B. DIMENSIONS OF PROPELLING CHARGES.	27
APPENDIX C. TABULATION OF FIRING DATA	31
APPENDIX D. PLOTS OF PRESSURES (SPINDLE AND FORWARD) AND PRESSURE DIFFERENCES VERSUS TIME.	35
DISTRIBUTION LIST.	77

LIST OF ILLUSTRATIONS

Figure		Page
1	High-Amplitude Pressure Waves Resulting from Improper Ignition of a 155-mm Propelling Charge (Zone 8)	10
2	155-mm, M203, Propelling Charge	12
3	Extreme Loading Configurations for the M203E1 Propelling Charge in the M198 Howitzer	16
4	155-mm, M198 Pressure-Wave Sensitivity, Zone 8 . . .	18
5	Dependence of Maximum Chamber Pressure on Conditioning Temperature for 7- and 19-Perforation Propellant Charges	19

LIST OF TABLES

Table		Page
I.	Summary of 21°C Firing Data	13
II.	Comparison of Firing Data for M203E1 Propelling Charges Fired as Received and after Reloading	13
III.	Summary of 63°C Firing Data	17
IV.	Summary of -51°C Firing Data	18

I. INTRODUCTION

Development of a Zone 8 propelling charge for the Army 155-mm Howitzers (M198 and now M109A2/A3 as well) has been, over the past half-dozen years, plagued by a number of problems, both minor and serious. Excessive pressures and even breechblows have been associated with large-amplitude pressure waves resulting from improper ignition of the main propellant charge[1]. (The presence of pressure waves in gun chambers is readily apparent upon examination of multi-station, pressure-time data or, perhaps more graphically, of the difference signal between two such pressure stations, as shown in Figure 1.) During this same period of time, several theoretical and experimental investigations[2-5] have suggested that the use of 19-perforation propellant grains as a replacement for the standard 7-perforation configuration would result in a propelling charge more forgiving to less-than-optimum ignition conditions, thereby reducing the occurrence of high-amplitude pressure waves and associated problems. Specific benefits indicated were: (1) lower nominal pressure-wave levels; (2) less round-to-round variability in pressure waves; and (3) less sensitivity of the maximum chamber pressure to variability in pressure waves. All studies seem to be in accord in that the suggested mechanism responsible for these benefits involves the reduction in initial surface area and the increase in bed permeability to gas flow accompanying the necessarily larger 19-perforation grains. These factors both tend to mitigate the formation of locally high pressures in the chamber.

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[1] *I.W. May, E.V. Clarke, and H. Hassmann, "A Case History: Gun Ignition Related Problems and Solutions for the XM-198 Howitzer," USA ARRADCOM, USA Ballistic Research Laboratory Interim Memorandum Report 150, Aberdeen Proving Ground, MD, October 1973 (No longer available).*

[2] *J.J. Rocchio, K.J. White, C.R. Ruth, and I.W. May, "Propellant Grain Tailoring to Reduce Pressure Wave Generation in Guns", Proceedings of the 12th JANNAF Combustion Meeting, CPIA Publication 273, December 1975.*

[3] *J.J. Rocchio, C.R. Ruth, and I.W. May, "Grain Geometry Effects on Wave Dynamics in Large Caliber Guns", Proceedings of the 13th JANNAF Combustion Meeting, CPIA Publication 281, December 1976.*

[4] *A.W. Horst, T.C. Smith, and S.E. Mitchell, "Key Design Parameters in Controlling Gun-Environment Pressure Wave Phenomena-Theroy vs. Experiment", Proceedings of the 13th JANNAF Combustion Meeting, CPIA Publication 281, December 1976.*

[5] *J.J. Rocchio and C.R. Ruth, "An Investigation of the Interior Ballistic Performance of a 19-Perforation, M30A1 Propellant Granulation in the Zone 8 Charge of the 155-mm, M198 Howitzer. USA ARRADCOM, USA Ballistic Research Laboratory Memorandum Report (Report in preparation) Aberdeen Proving Ground, MD.*

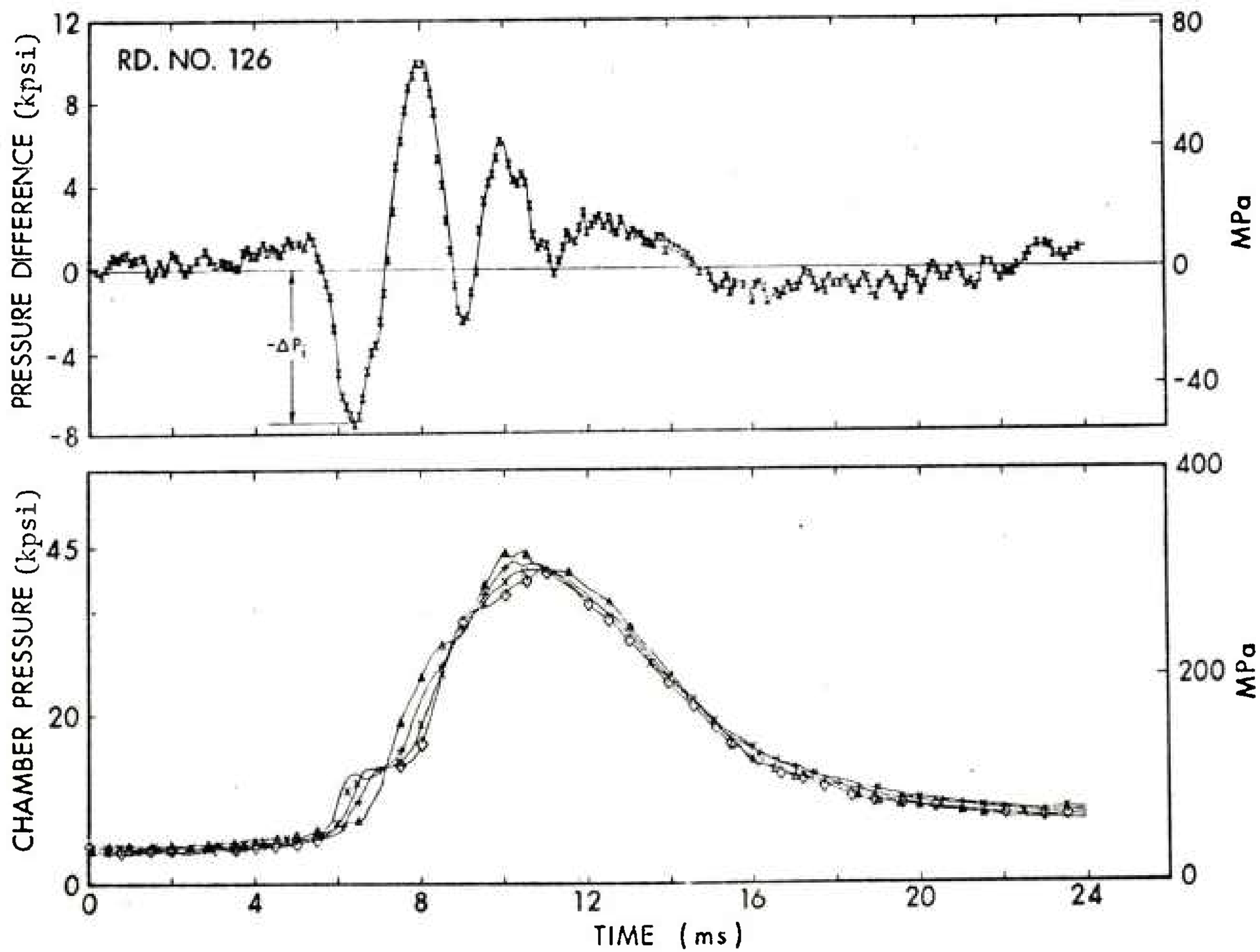

Figure 1. High-Amplitude Pressure Waves Resulting from Improper Ignition of a 155-mm Propelling Charge (Zone 8)

An experimental investigation was thus undertaken to examine the potential benefits of a direct substitution of 19-perforation propellant for 7-perforation propellant in the M203E1 Propelling Charge. (This configuration is essentially similar to that of the M203 Propelling Charge, shown in Figure 2.) In particular, ballistic performance of the two charges at temperature extremes (-51°C and + 63°C) and at maximum charge standoff from the spindle face (up to 150 mm with the M483A1 Projectile in the M199 Cannon) was investigated. These firing conditions had been previously shown to be most conducive to the formation of pressure waves or to apparent coupling between pressure waves and increases in maximum chamber pressure.

II. TESTING

M203E1 Propelling Charges, Lot IND-78-F-069805, and M483A1 Projectiles, Lots LSDZ 3989 and LSDZ 4183, were supplied for testing by the Office of the Project Manager, Cannon Artillery Weapons Systems (PM/CAWS). A 450-kg lot of 19-perforation propellant, M30A1, was produced at the Radford Army Ammunition Plant (See Appendix A). Grain dimensions were selected based on the results of previous firings[5].

Test charges were fabricated by unloading standard M203E1 charges and reloading with 19-perforation propellant. A brief probing series (Round Ident. No. 5-10) resulted in the selection of an 11.97-kg (26.4-lb) charge, compared to an 11.86-kg (26.15-lb) charge for the 7-perforation propellant. In addition, a 21°C (70°F) firing series was included in which half the standard 7-perforation charges were unloaded and then reloaded to determine whether or not non-standard production procedures at Aberdeen Proving Ground would introduce any performance variations. Critical measurements of selected charges before and after reloading are included as Appendix B.

All firings were conducted at the Ballistic Research Laboratory Sandy Point Firing Facility in an M185 Cannon modified to provide critical cannon dimensions similiar to those of the M199 Cannon. Multiple-station pressure data, pressure-difference data, and projectile velocities were recorded digitally by the Ballistic Data Acquisition System (BALDAS) as well as on backup analog magnetic tape.

III. RESULTS AND DISCUSSION

Firing data are tabulated in Appendix C, with computer-generated plots of selected data channels (spindle and forward pressures vs. time; pressure-difference vs. time) included as Appendix D.

A. Nominal Performance Characteristics

Initial firings at the assessed charge weights were conducted at 21°C and with the nominal 25-mm standoff between the propelling charge and the spindle face. As indicated by summary data provided in Table

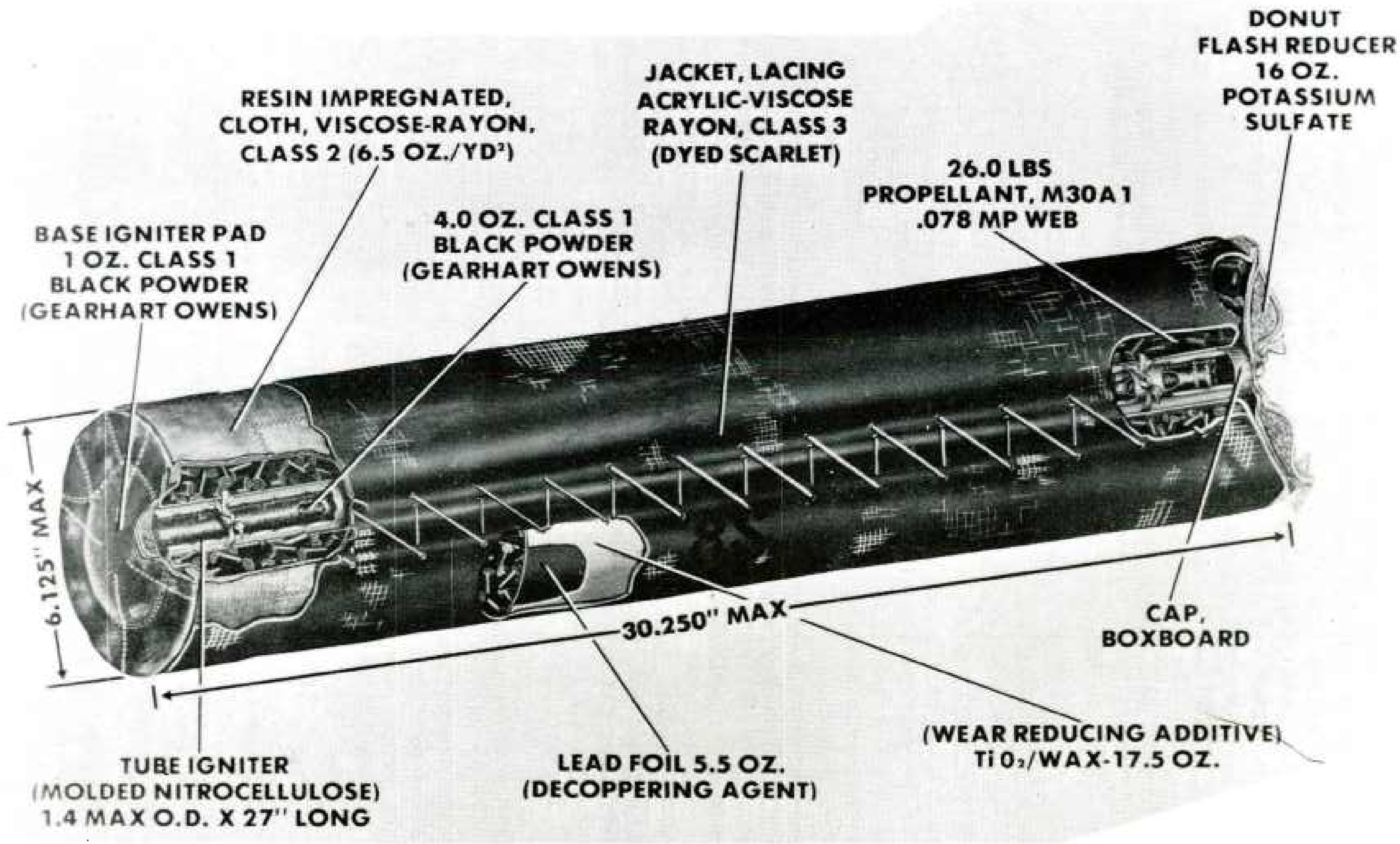

Figure 2. 155-mm, M203, Propelling Charge

I, the 19-perforation propellant charges performed similarly to the 7-perforation propellant charges in terms of all measured parameters.

TABLE I. SUMMARY OF 21°C FIRING DATA*

Parameter	7-Perf	19-Perf
Muzzle Velocity	790 m/s (2.4)	793 m/s (0.9)
Maximum Chamber Pressure	331 MPa (6.9)	328 MPa (2.7)
Initial Reverse Pressure-Difference, ($-\Delta P_i$)	6 MPa (8.0)	10 MPa (3.7)
Ignition Delay	67 ms (8.8)	59 ms (6.1)

*Values provided are 6-round averages; sample standard deviations shown in parentheses. Firings conducted using inert, M483A1 Projectiles.

In addition, there was no discernable degradation in the performance of the M203E1 Propelling Charges after reloading at Aberdeen Proving Ground (see Table II).

TABLE II. COMPARISON OF FIRING DATA FOR M203E1 PROPELLING CHARGES FIRED AS RECEIVED AND AFTER RELOADING*

Parameter	As Received	After Reloading
Muzzle Velocity	790 m/s (3.1)	789 m/s (2.1)
Maximum Chamber Pressure	333 MPa (8.5)	329 MPa (6.1)
Initial Reverse Pressure-Difference ($-\Delta P_i$)	9 MPa (11.6)	3 MPa (2.5)
Ignition Delay	70 ms (6.7)	63 ms (10.2)

*Values provided are averages for two 3-round groups, which together comprise the 21°C, 7-Perf. sample described in Table I.

Of concern, however, was the fact that a reduction in the level of pressure waves did not accompany introduction of the larger 19-perforation propellant grains, as seen in previous investigations and as suggested by theoretical considerations mentioned earlier. An explanation for this result may be provided by recent theoretical[6] and experimental[7] investigations of bagged-charge phenomenology, in which annular ullage external to the bag was shown to play a major role during the flamespread portion of the interior ballistic cycle, equilibrating longitudinal pressure gradients and perhaps significantly reducing the stagnation event at the projectile base. The importance of propellant bed permeability in terms of the formation of longitudinal pressure waves may thus be somewhat mitigated. Much of the previous data cited indicating substantial reductions in pressure waves was generated using full-bore propellant charges - a configuration which requires that any locally high pressures be equilibrated through the propellant bed itself and renders bed permeability a critical parameter. Other such data were for undersized bagged charges fired at zero standoff from the spindle face. Perhaps this condition as well reduces the effectiveness of annular ullage; however, these remarks are speculative at this time.

It might be inferred from these data that for undersized, centercore-ignited configurations such as the M203E1, no real benefits are to be expected from use of a 19-perforation propellant granulation, at least not in terms of pressure waves. We must remember, however, that history has provided us with an abundance of data attesting to the variability of bagged-charge performance, particularly with respect to pressure waves. All of the sources of this variability are not well known, but should this annular "pressure-relief" path be insufficient to compensate for faulty igniter performance or be lost prematurely because of an untimely bag rupture, propellant bed permeability to gas flow will again become critical. A potential benefit may then be the increased "forgivability" of the larger 19-perforation propellant granulation to other propelling charge deficiencies, both known and unknown. An indication of this behavior may be found in the consistently smaller sample standard deviations in all performance parameters exhibited by the 19-perforation propellant charges. Indeed, the increased $-\Delta P_i$ level of Round Ident. No. 16 (see Appendix D) might just be the result of some latent flaw which manifests itself as stronger pressure waves in the standard M203E1 charge.

B. High-Temperature Firings

A comparison of performances for 7- and 19-perforation propellants in the M203E1 bagged-charge geometry was also made at the high temperature firing limit (+ 63°C). These data were required in order to assess pressure-wave characteristics of hot charges and to obtain comparative

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[6] *P. S. Gough, "Theoretical Study of Two-Phase Flow Associated with Granular Bag Charges", USA ARRADCOM, USA Ballistic Research Laboratory Contract Report No. 00381, September 1978, Aberdeen Proving Ground, MD,* AD #A062144.

[7] *T.C. Minor, A. W. Horst, and J. R. Kelso, "Experimental Investigation of Ignition-Induced Flow Dynamics in Bagged-Charge Artillery", Proceedings of the 15th JANNAF Combustion Meeting, December 1978.*

temperature coefficient data. A considerable body of data for several types of propelling charges had shown pressure-wave levels to increase with temperature[8-9].

Firings over the past year had also revealed that, at least for the M203E1 Propelling Charge, pressure waves increased significantly as charge standoff from the spindle face (depicted in Figure 3) was increased beyond a certain point. This behavior may result from a less efficient coupling between the primer and the igniter centercore at large standoff distances, leading to more localized ignition at the base of the charge. The maximum charge standoff with the M483A1 Projectile (150 mm) appeared to be the most aggravating test condition (in terms of pressure-waves), so all hot firings were conducted with this configuration. The decision necessarily compromised the universality of temperature-coefficient data obtained, since the 21°C firings were conducted with 25-mm charge standoff, and ballistic level had been previously shown to be affected by standoff. Direct comparison between the 7- and 19-perforation propellant charges is still useful in developing relative temperature coefficients.

Unfortunately, during the procedure to condition the 19-perforation propellant charges to + 63°C, a faulty thermocouple device led to a conditioning temperature of + 74°C. The charges were subsequently cooled after one unintentional firing at this temperature; however, the loss of residual solvents, particularly near the surface of the grains could have significantly affected propellant ignitability and burning rates. It should be noted, as well, that this four-day conditioning/re-conditioning procedure took place with the charges removed from their shipping cans, a limitation imposed by the size of the temperature box employed. Some melting of the wax in the wear-reducing liners was evident, but tear-down of one of the charges revealed no contamination of propellant or black powder.

The data presented in Table III indeed suggest that the propellant was affected in some manner by the unplanned overheating. The increase in pressure levels from those for the 21°C firings is approximately 50 percent greater for the 19-perforation propellant charges than for the standard M203E1 charges. However, data generated previously at BRL using 19-perforation propellant manufactured at RAAP using the same propellant dies and loaded into the XM123E2 Interim Charge (a precursor to the

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[8] *"Engineer Design Test for M188E1 Propelling Charge (Zone 9) for 8-Inch Howitzer, M201 Cannon with Muzzle Brake", US Army Aberdeen Proving Ground Firing Record No. P-82599, Aberdeen Proving Ground, MD, 8 July 1977.*

[9] *"Ballistic Evaluation of M30A1 Propellant for 155-mm, M203 Charge," US Army Aberdeen Proving Ground Firing Record No. P-82772, Aberdeen Proving Ground, MD, 27 March 1979.*

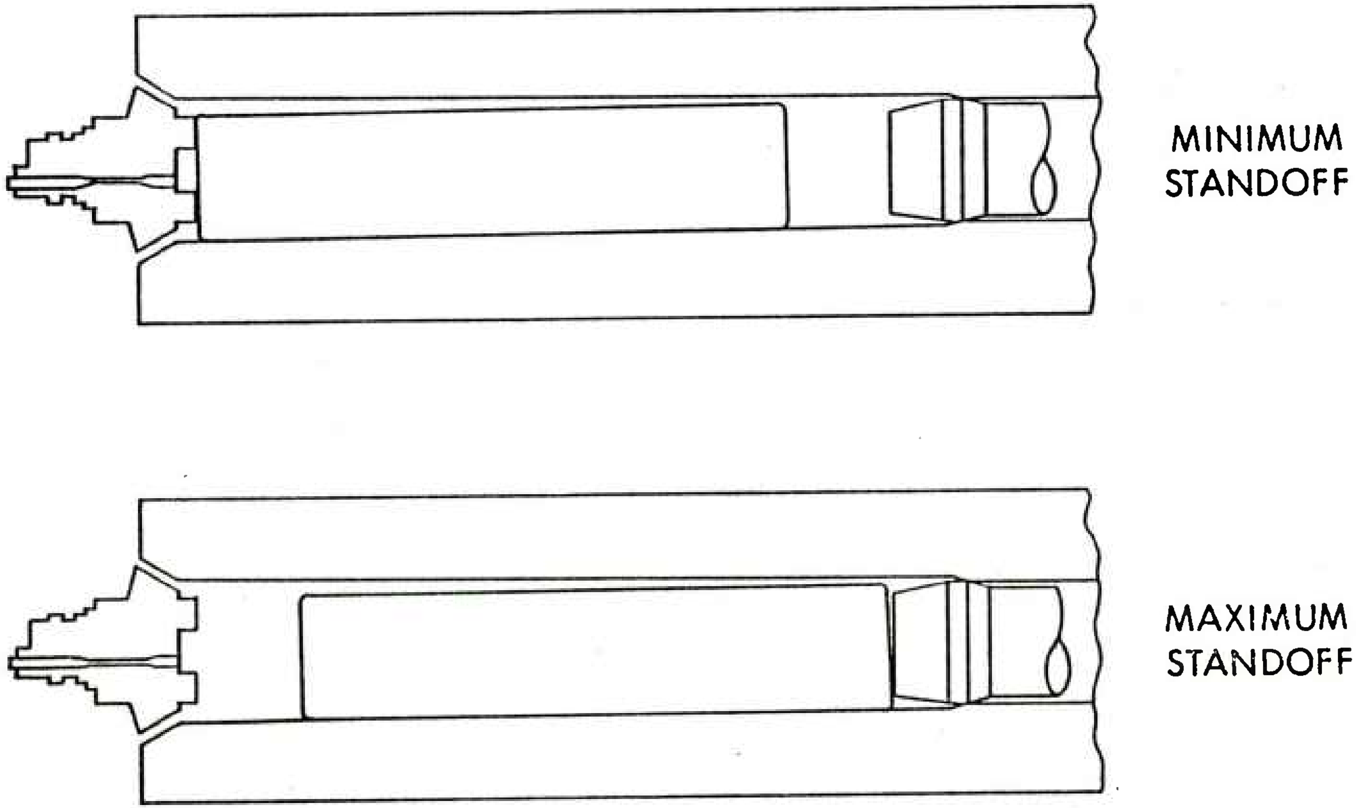

Figure 3. Extreme Loading Configurations for the M203E1 Charge in the M198 Howitzer

M203) provided the same temperature coefficient as did unmodified XM123E2 Interim Charges fired under the same conditions[5].

TABLE III. SUMMARY OF 63°C FIRING DATA*

Parameter	7-Perf	19-Perf
Muzzle Velocity	833 m/s (6.5)	823 m/s (1.8)
Maximum Chamber Pressure	378 MPa (3.6)	402 MPa (2.5)
Initial Reverse Pressure-Difference, ($-\Delta P_i$)	17 MPa (6.9)	10 MPa (2.3)
Ignition Delay	68 ms (5.8)	90 ms (16.8)

*Values provided are 6-round averages; sample standard deviations shown in parentheses. Firings conducted using inert, M483A1 Projectiles.

In terms of pressure-wave characteristics, the average $-\Delta P_i$, is seen to be nearly halved with the introduction of the 19-perforation propellant, with an even greater reduction in the accompanying standard deviation. Perhaps with the increased gas generation rates accompanying the higher temperatures, annular flow no longer is sufficient to dominate the process of pressure equilibration, and bed permeability is again of importance.

C. Low-Temperature Firings

Firings were also conducted to compare performance of the 7- and 19-perforation propellant charges at the low temperature extreme (-51°C). While pressure-wave levels are typically quite small at low temperatures, several breechblows have occurred with cold charges. In addition, sensitivity firings of intentionally faulted charges have shown a stronger feedback from pressure waves into the maximum chamber pressure to exist for cold than for ambient charges (see Figure 4). A mechanism involving grain fracture resulting from impact against the projectile base and perhaps even the spindle face has been suggested[10], certainly a process expected to be more pronounced at cold temperatures[11]. Nevertheless, as seen in the summary data of Table IV, acceptable performance was exhibited by both configurations at -51°C, though a

[10] *A. W. Horst, I. W. May, and E. V. Clarke, "The Missing Link Between Pressure Waves and Breechblows", USA ARRADCOM, USA Ballistic Research Laboratory Memorandum Report No. 02849, July 1978, Aberdeen Proving Ground, MD.* AD#A058354

[11] *P. Benhaim, J. L. Paulin, and B. Zeller, "Investigation of Gun Propellants Breakup and Its Effects in Interior Ballistics", Proceedings of the Fourth International Symposium on Ballistics, 17-19 October 1978.*

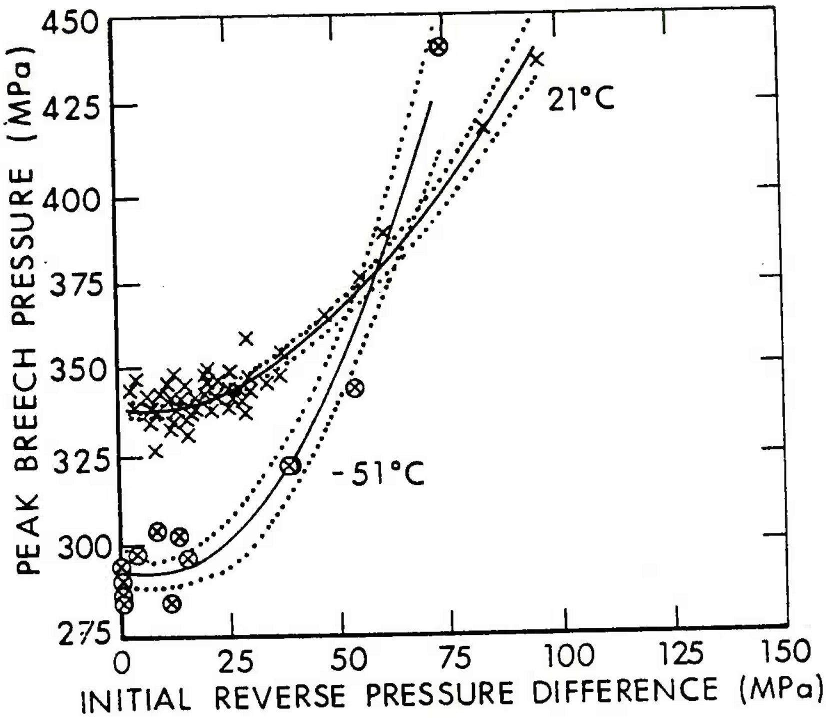

Figure 4. 155-mm, M198 Pressure-Wave Sensitivity, Zone 8

TABLE IV. SUMMARY OF -51°C FIRING DATA*

Parameter	7-Perf	19-Perf
Muzzle Velocity	765 m/s (2.2)	766 m/s (1.2)
Maximum Chamber Pressure	308 MPa (6.2)	299 MPa (3.3)
Initial Reverse Pressure-Difference, $(-\Delta P_i)$	3 MPa (1.2)	2 MPa (1.2)
Ignition Delay	131 ms (5.8)	122 ms (12.7)

*Values provided are 6-round averages; sample standard deviations shown in parentheses. Firings conducted using inert, M483A1 Projectiles.

stronger dependence of pressure on temperature again accompanied use of the 19-perforation propellant. The dependence of maximum chamber pressure on conditioning temperature for propelling charges fired during this program is depicted in Figure 5. Low-temperature data suggests that the excessive high-temperature sensitivity of the 19-perforation propellant changes may not be solely the result of overheating. However, other contributors are unknown at this time.

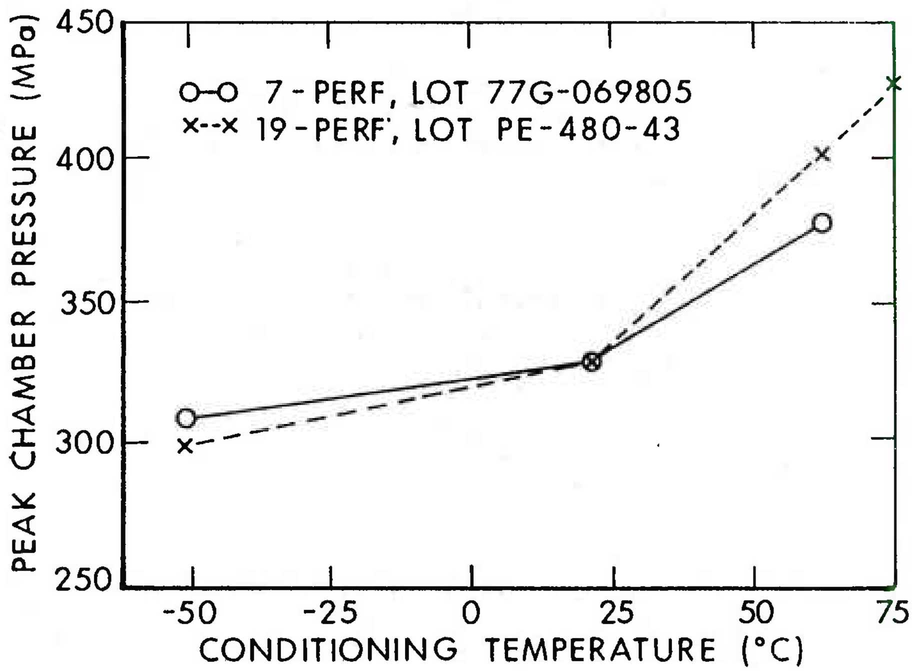

Figure 5. Dependence of Maximum Chamber Pressure on Conditioning Temperature for 7- and 19-Perforation Propellant Charges

IV. CONCLUSIONS AND RECOMMENDATIONS

Based on the experimental investigation described in this report, the following conclusions are drawn:

1. M30A1 propellant can be manufactured in a 19-perforation granulation and loaded into an M203E1 Propelling Charge configuration to provide ballistically equivalent performance to that of the standard M203E1 Charge under nominal firing conditions (21°C, 25-mm standoff). Velocity uniformity, ignition delays, and pressure-wave characteristics appear to be essentially unaffected.

2. No differences in performance between the two charge configurations are revealed by -51°C firings with maximum charge standoff as allowed by the M483A1 Projectile.

3. No increase in pressure-wave levels accompanying high temperature firings with maximum charge standoff was observed for the 19-perforation propellant. This is in contrast to a doubling of the mean initial reverse-pressure difference for the standard M203E1 Charge when going from 21°C (25-mm standoff) to 63°C (∿150-mm standoff).

4. An extremely high temperature coefficient was observed for the 19-perforation propellant charges fired in this program. This result is not consistent with previous data and may not be representative because of the accidental overheating of the 19-perforation propellant shortly before firing.

5. A reduction in the variability of pressure waves and, indeed, of accompanying velocity and maximum chamber levels appears to be associated with use of the 19-perforation propellant. This result is, of course, somewhat conjectural because of sample sizes.

The above conclusions may be revealing in terms of developing a comprehensive understanding of bagged-charge phenomenology. Certainly, the question concerning the temperature coefficient needs to be resolved. Of potentially more use to the charge designer is the added insight provided by these results regarding the relative importance of propellant geometry versus charge geometry. The direct substitution of the 19-perforation propellant geometry in the M203E1 or similar propelling charge should reduce the sensitivity of the charge to manufacturing, loading, and firing perturbations. As such, pursuit of a 19-perforation propellant M203E1 is recommended if a product improvement is required within a relatively short term. It must be emphasized that really significant advances, however, may require modification to both propellant and charge geometries, involving possibly substantial changes to igniter and packaging elements.

ACKNOWLEDGMENTS

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6. P.S. Gough, "Theoretical Study of Two-Phase Flow Associated with Granular Bag Charges", USA ARRADCOM, USA Ballistic Research Laboratory Contract Report No. 00381, September 1978, Aberdeen Proving Ground, MD. AD #A062144.

7. T.C. Minor, A.W. Horst, and J.R. Kelso, "Experimental Investigation of Ignition-Induced Flow Dynamics in Bagged-Charge Artillery", Proceedings of the 15th JANNAF Combustion Meeting, December 1978.

8. "Engineer Design Test for M188E1 Propelling Charge (Zone 9) for 8-Inch Howitzer, M201 Cannon with Muzzle Brake", US Army Aberdeen Proving Ground Firing Record No. P-82599, Aberdeen Proving Ground, MD, 8 July 1977.

9. "Ballistic Evaluation of M30A1 Propellant for 155-mm, M203 Charge," US Army Aberdeen Proving Ground Firing Record No. P-82772, Aberdeen Proving Ground, MD, 27 March 1979.

10. A.W. Horst, I.W. May, and E.V. Clarke, "The Missing Link Between Pressure Waves and Breechblows", USA ARRADCOM, USA Ballistic Research Laboratory Memorandum Report No. 02849, July 1978, Aberdeen Proving Ground, MD. AD #A058354.

11. P. Benhaim, J.L. Paulin, and B. Zeller, "Investigation of Gun Propellants Breakup and Its Effects in Interior Ballistics", Proceedings of the Fourth International Symposium on Ballistics, 17-19 October 1978.

APPENDIX A

PROPELLANT DESCRIPTION SHEETS

PROPELLANT DESCRIPTION SHEET

CORRECTED COPY*

U.S. Army Lot No. RAD77G-069805

Composition No. M30A1 for Use in Propelling Charge M203, f/155mm How., M198

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA.

Packed Amount 320,975 lbs

Contract No. DAAA09-77-C-4007 Date 4-1-77

Specification No. MIL-P-48367A

NITROCELLULOSE

ACCEPTED BLEND NUMBERS

C-35,556; 557; 558; 565; 566; 570; 573; 576; 577; 579

	Nitrogen Content	KI Starch (65.5°C)	Stability (134.5°C)
Maximum	12.60 %	Mins	Mins
Minimum	12.50 %	Mins	Mins
Average	12.56 %	45+ Mins	30+ Mins
			Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound ~~XX~~ 12 Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds ACETONE per 100 Pounds Solvent

Percentage Remains to Whole

Temperatures °F From	To	PROCESS-SOLVENT RECOVERY AND DRYING	Time Days	Hours
		Load Forced Air Dry at Ambient Temperature		
Ambient	140	Increase Temperature 5°F per Hour		
140	140	Hold at Temperature		72

TESTS OF FINISHED PROPELLANT

PROPELLANT COMPOSITION Constituent	Percent Formula	Percent Tolerance	Percent Measured	STABILITY AND PHYSICAL TESTS	Formula	Actual
Nitrocellulose	28.00	±1.30	27.18	Heat Test S.P. 120°F	NO CC 40'	60'
Nitroglycerin	22.50	±1.00	22.80	No Fumes	- - -	60'
Nitroguanidine	47.00	±1.00	47.54	Form of Propellant, Type I		Cylinder
Ethyl Centralite	1.50	±0.10	1.55	No. of Perforations		7
Potassium Sulfate	1.00	±0.30	0.93			
TOTAL	100.00		100.00			
Graphite Glaze (added)	0.15	Max.	0.08			
Total Volatiles	0.50	Max.	0.33			

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD77G-069805	+90	96.51 %	99.74 %
	RAD77G-069805	-40	92.58 %	98.16 %
Standard	RAD-E-14		100.00%	100.00%

Remarks

FIRED IN ACCORDANCE WITH MIL-STD-286B, METHOD 801.1, IN A NOMINAL SIZE 700 CC CLOSED BOMB. TEST FOR INFORMATIONAL PURPOSES ONLY.

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)		0.949	0.9481	6.25 Max.	1.08
Diameter (D)		0.470	0.4173	3.125 Max.	1.28
Perf. Dia (d)		0.039	0.0338		
WEB					
Inner		0.0930	0.0793		
Outer		0.0845	0.0806		
Average		0.0888	0.0800		
Web Difference/Std. Dev. in % of Web Average	15 Max.		2		
L/D	2.10 to 2.50		2.27		
D/d	5.0 to 15		12.4		

DATES	
Packed	7-20-77
Sampled	7-20-77
Test Finished	7-27-77
Offered	8-18-77
Description Sheets Forwarded	8-23-77

Type of Packing Container FIBER DRUMS PER MIL-STD-652C WITH NOTICE 1

Remarks This is the first propellant lot using toluene as an alcohol denaturant.
*Issued to replace description sheet dated 8-10-77 to add statement concerning type of alcohol denaturant used.

THIS LOT MEETS ALL THE CHEMICAL AND PHYSICAL REQUIREMENTS OF THE APPLICABLE SPECIFICATION.

Contractor's Representative: H. C. Dickinson H.C. Dickinson

Government Quality Assurance Representative: JAMES E. BLAND James E Bland

RAD FORM (Orig. 7/76)

PROPELLANT DESCRIPTION SHEET

U S Army Lot No. RAD-PE-480-43 Composition No. M30A1 19MP

Manufactured at RADFORD ARMY AMMUNITION PLANT, RADFORD, VA. Packed Amount 978 lbs.

Contract No DAAA09-77-C-4007 Date 4-1-77 Specification No COR letter SARRA-IE, dated 5/18/78

NITROCELLULOSE

Accepted Blend Numbers	Nitrogen Content		KI Starch (65.5°C)	Stability (134.5°C)
C-35,996	Maximum	%	Mins	Mins
	Minimum	%	Mins	Mins
	Average	12.60 %	- Mins	30 Mins
				Explosion Mins

MANUFACTURE OF PROPELLANT

0.22 Pounds Solvent per Pound NC/Dry Weight Ingredients Consisting of 60 Pounds Alcohol and 40 Pounds acetone per 100 Pounds Solvent

Percentage Remix to Whole 50

PROCESS-SOLVENT RECOVERY AND DRYING

Temperatures °C From	To		Time Days	Hours
		Load forced air dry at ambient temperature		
Ambient	140	Increase temperature 5°F per hour		12
140	140	Hold at temperature		100

TESTS OF FINISHED PROPELLANT

Propellant Composition Constituent	Percent Formula	Percent Tolerance	Percent Measured
Nitrocellulose	28.00	± 1.30	28.44
Nitroglycerin	22.50	± 1.00	21.21
Nitroguanidine	47.00	± 1.00	47.72
Ethyl Centralite	1.50	± 0.10	1.53
Potassium Sulfate	1.00	± 0.10	1.10
TOTAL	100.00		100.00
Total Volatiles	0.50	Max	0.12
Graphite Glaze	0.2	Max	0.09

Stability and Physical Tests	Formula	Actual
Heat Test SP, 120°C	No CC 40'	60"+
No fumes		1 hr
Form of Propellant		Cyld
No. Perforations		19
Density, gm/cc	N/A	1.674
Heat of Explosion, cal/gm	N/A	966.2

CLOSED BOMB

	Lot Number	Temp °F	Relative Quickness	Relative Force
Test	RAD-PE-480-43	+90	98.79	98.48
	RAD-PE-480-43	-40	94.74	96.65
Standard	RAD-E-1	+90	100.00%	100.00%

Remarks

Fired in accordance with MIL-STD-286B, Method 801.1, in a nominal size 700cc closed bomb. Test for informational purposes only. Loading Density was 0.2 gm/cc

PROPELLANT DIMENSIONS (inches)

	Specification	Die	Finished	Mean Variation in % of Mean Dimensions Spec.	Actual
Length (L)	1.59 nom	1.595	1.632	N/A	1.45
Diameter (D)		0.703	0.615	N/A	--
Perf Dia. (d)		0.044	0.0384		
Web, Avg	0.071, Nom.	0.0822	0.0706		
Inner		0.0930	0.0726		
Outer(1)		0.0880	0.0719		
Outer(2)		0.0655	0.0672		
Web Difference/ Std. Dev. in % of Web Average	10% Max	0	4.16		
L/D	2.5 Nom	2.27	2.64		
D/d	15.5 Nom	15.98	16.06		

DATES	
Packed	6/12/78
Sampled	6/12/78
Test Finished	7/10/78
Offered	7/10/78
Description Sheets Forwarded	7/12/78

Type of Packing Container Fiber Drums: 6 @ 150 lbs. net; 1 @ 70 lbs. net.

Remarks

This lot meets all the chemical and physical requirements of the applicable specification, except for nitroglycerin content.

Contractor's Representative R. A. Williams

R. A. Williams

Government Quality Assurance Representative for James E. Bland

SMU FORM 1047R MARCH 1971

APPENDIX B

DIMENSIONS OF PROPELLING CHARGES

DIMENSIONS OF 7-PERF. CHARGES

	Before Unloading		After Reloading	
Ident. No.	Length (cm)	Diam. (cm)	Length (cm)	Diam. (cm)
15	72.4	15.2	74.2	15.2
18	72.1	15.2	74.4	14.7
20	73.4	15.0	74.9	15.0
55	72.4	15.2	74.9	15.0
56	71.9	15.2	73.4	14.7
57	72.4	15.0	74.2	15.0
Average:	72.4	15.1	74.3	14.9
Std. Dev:	(0.52)	(0.10)	(0.56)	(0.20)

DIMENSIONS OF CHARGES AS FIRED

7-Perf.			19-Perf.		
Ident. No.	Length (cm)	Diam. (cm)	Ident. No.	Length (cm)	Diam. (cm)
6	72.4	15.2	8	73.0	15.7
7	72.4	15.2	9	72.6	15.9
11	72.4	15.2	10	73.0	15.8
13	72.4	15.2	22	75.4	15.2
15	74.2	15.2	23	75.7	15.2
16	72.4	15.2	24	75.9	15.2
18	74.4	14.7	25	75.4	15.2
19	72.4	15.2	26	75.7	15.2
20	74.9	15.0	27	76.0	15.4
30	72.4	15.2	38	75.7	15.2
31	72.4	15.2	40	75.2	15.2
32	72.4	15.2	41	75.4	15.2
33	72.4	15.2	42	75.4	15.2
34	72.4	15.2	43	76.2	15.6
35	72.4	15.2	44	75.4	15.2
36	72.4	15.2	45	76.0	15.5
51	72.4	15.2	46	75.7	15.2
52	72.4	15.2	47	76.0	15.2
53	72.4	15.2	59	75.2	15.2
54	72.4	15.2	60	75.7	15.2
55	74.9	15.0	61	74.7	15.2
56	73.4	14.7	62	75.7	15.2
57	74.2	15.0	63	75.4	15.2
			64	75.2	15.2
			65	75.4	15.2

APPENDIX C

TABULATION OF FIRING DATA

FIRING DATA

7-Perforation M30A1

MAX. CHAMBER PRESSURE (MPa)

IDENT. NO.	CHG. WT. (kg)	PROJ. WT. (kg)	SO (cm)	T (°C)	SEATING (cm)		VELOCITY (m/sec)	Spindle P_1	Spindle P_2	Mid P_3	Mid P_4	Forward P_5	Forward P_6	IGN. DELAY (ms)	$-\Delta P_i$ (MPa)
5	11.86	43.00	2.5	+21	89.9		825	328	322	+	+	309	310	+	+
6		43.10	2.5	+21	89.8		828	333	320	+	+	312	315	+	+
10		43.20	2.5	+21	89.3		819	318	314	+	+	311	310	+	+
						(Avg.)	824	326	319			311	312		
						(Std. Dev.)	(4.6)	(7.6)	(4.2)			(1.5)	(2.9)		
13	11.86	47.08	2.5	+21	94.8		787	314	324	310	296	300	295	69	1
15		47.08	2.5	+21	94.7		787	314	322	307	299	303	299	72	3
16		46.90	2.5	+21	94.8		793	305	341	317	301	306	305	78	22
18		47.13	2.5	+21	94.8		790	291	333	309	295	*	298	52	1
19		47.13	2.5	+21	94.9		789	300	333	308	294	300	297	65	3
20		46.99	2.5	+21	94.8		791	302	332	309	295	302	297	65	6
						(Avg.)	790	304	331	310	297	302	299	67	6
						(Std. Dev.)	(2.4)	(8.8)	(6.9)	(3.6)	(2.7)	(2.5)	(3.5)	(8.8)	(8.0)
30	11.86	47.13	17.8	+63	94.7		825	378	376	373	348	363	358	71	27
31		47.13	15.2	+63	94.7		826	383	380	366	349	361	359	72	19
32		46.95	16.5	+63	94.7		837	383	381	359	348	359	354	75	11
33		46.95	15.5	+63	94.9		844	383	381	359	337	368	363	65	24
34		46.99	16.2	+63	94.9		834	*	371	372	351	361	360	70	12
35		46.67	14.6	+63	94.7		833	379	379	366	348	361	356	61	14
36		47.08	16.5	+63	94.6		833	378	379	374	348	362	358	60	9
						(Avg.)	833	381	378	367	347	362	358	68	17
						(Std. Dev.)	(6.5)	(2.6)	(3.6)	(6.3)	(4.6)	(2.9)	(2.9)	(5.8)	(6.9)
51	11.86	46.77	14.0	-51	94.7		762	302	*	295	283	283	280	136	4
52		47.08	14.0	-51	94.7		763	302	303	294	284	284	281	134	3
53		46.86	14.6	-51	94.8		764	299	302	292	281	278	275	125	2
54		46.49	14.0	-51	94.7		767	300	307	300	288	287	285	123	3
55		46.81	14.0	-51	94.7		768	314	317	298	287	289	286	131	1
56		47.08	13.3	-51	94.7		766	311	311	295	286	288	282	137	4
57		46.99	14.0	-51	94.8		766	θ	θ	θ	θ	θ	θ	θ	θ
						(Avg.)	765	305	308	296	285	285	282	131	3
						(Std. Dev.)	(2.2)	(6.3)	(6.2)	(2.9)	(2.6)	(4.1)	(3.9)	(5.8)	(1.2)

* Faulty gauge; data not recorded
θ Unexpected ignition delay; missed time window for digital recording
\+ Data not reduced

FIRING DATA

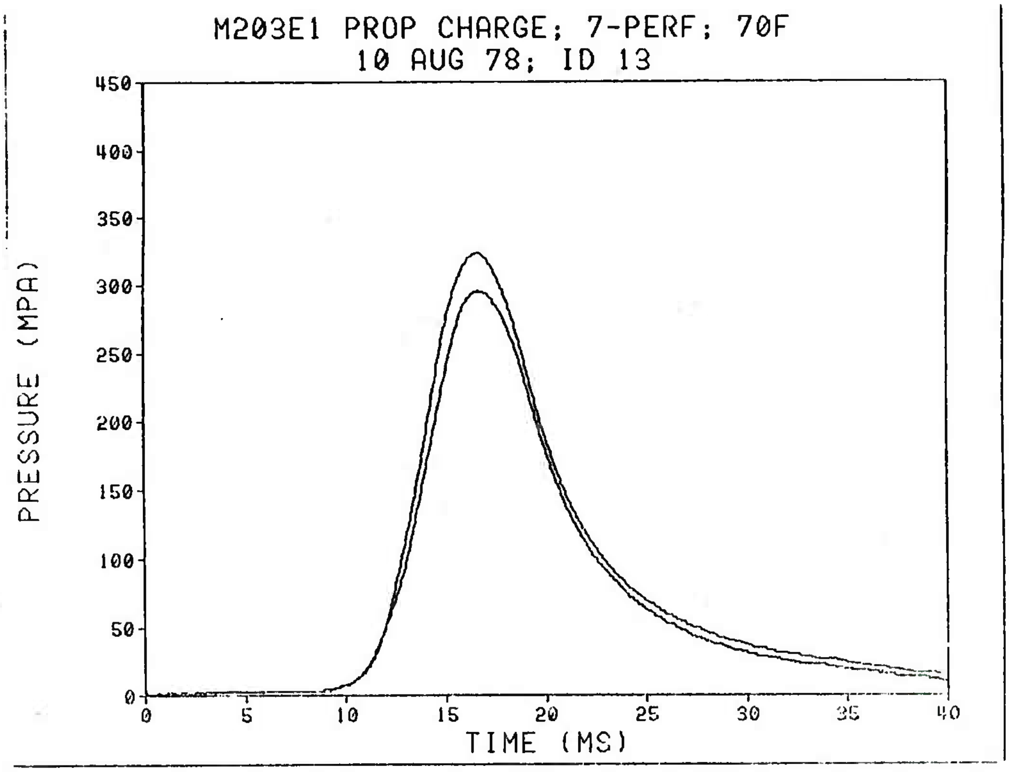
19-Perforation M30A1

IDENT. NO.	CHG. WT. (kg)	PROJ. WT. (kg)	SO (cm)	T (°C)	SEATING (cm)		VELOCITY (m/sec)	MAX. CHAMBER PRESSURE (MPa) Spindle P_1	P_2	Mid P_3	P_4	Forward P_5	P_6	IGN. DELAY (ms)	$-\Delta P_i$ (MPa)
7	11.79	43.08	2.5	+21	89.7		813	309	314	+	+	302	304	+	+
8	12.02	43.17	2.5	+21	89.7		828	328	325	+	+	324	318	+	+
9	12.02	43.18	2.5	+21	89.5		838	327	330	+	+	324	319	+	+
22	11.97	46.90	2.5	+21	94.8		792	293	326	317	299	312	308	63	14
23		46.90	2.5	+21	94.9		794	328	327	323	307	316	312	64	14
24		47.04	2.5	+21	94.8		793	334	332	321	307	315	312	63	7
25		47.04	2.5	+21	94.8		794	324	330	321	307	313	310	63	9
26		47.04	2.5	+21	94.8		792	318	325	315	299	308	306	52	5
27		47.08	2.5	+21	94.8		793	318	330	319	305	312	307	51	10
						(Avg.)	793	319	328	319	304	313	309	59	10
						(Std. Dev.)	(0.9)	(14.2)	(2.7)	(2.9)	(4.0)	(2.8)	(2.6)	(6.1)	(3.7)
38	11.97	46.90	13.7	+74	94.7		834	427	427	411	*	405	400	74	14
40	11.97	46.95	13.3	+63	94.7		825	410	407	394	*	387	380	61	12
41		46.95	14.1	+63	94.7		821	θ	θ	θ	θ	θ	θ	θ	θ
42		47.04	14.0	+63	94.6		820	402	402	387	*	384	379	93	10
43		46.77	13.3	+63	94.7		822	404	402	384	*	382	375	109	7
44		46.95	14.0	+63	94.7		825	413	401	385	*	383	378	81	13
45		46.81	13.3	+63	94.7		823	405	399	383	*	381	374	109	10
46		46.99	14.0	+63	94.7		823	409	401	384	*	381	376	91	7
47		46.81	14.0	+63	94.8		822	407	402	384	*	381	375	83	10
						(Avg.)	823	407	402	386		383	377	90	10
						(Std. Dev.)	(1.8)	(3.8)	(2.5)	(3.8)		(2.2)	(2.3)	(16.8)	(2.3)
59	11.97	46.95	14.0	-51	94.7		767	θ	θ	θ	θ	θ	θ	θ	θ
60		46.77	14.0	-51	94.7		765	292	+	+	+	292	+	113	0
61		47.04	14.6	-51	94.7		766	316	+	+	+	293	+	113	3
62		46.86	14.0	-51	94.7		767	313	299	+	+	274	276	132	2
63		46.90	14.0	-51	94.8		764	298	295	+	+	273	273	143	3
64		46.95	14.0	-51	94.8		766	312	303	+	+	276	275	121	1
65		46.72	14.6	-51	94.8		767	293	298	+	+	271	272	112	2
						(Avg.)	766	304	299			280	274	122	2
						(Std. Dev.)	(1.2)	(10.9)	(3.3)			(10.0)	(1.8)	(12.7)	(1.2)

* Faulty gauge; data not recorded
θ Unexpected ignition delay; missed time window for digital recording
\+ Data not reduced

APPENDIX D

PLOTS OF PRESSURES (SPINDLE AND FORWARD) AND PRESSURE-DIFFERENCES VERSUS TIME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10 AUG 78; ID 13
PRESSURE (MPA)
TIME (MS)
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150
200
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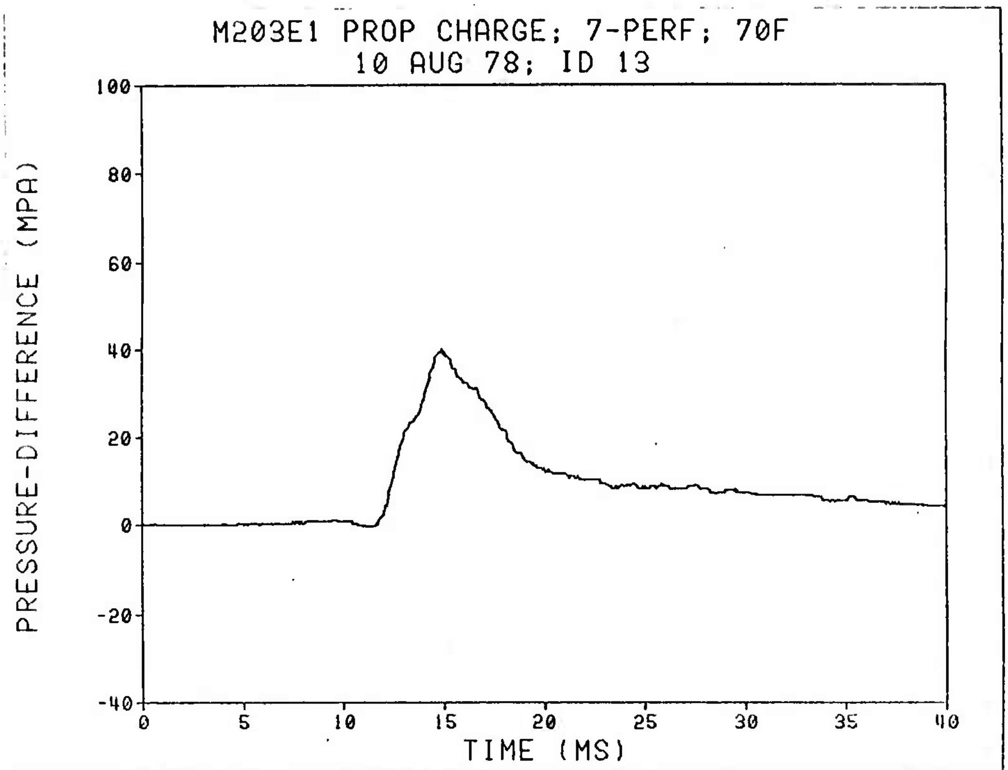
300
350
400
450
0
5
10
15
20
25
30
35
40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10 AUG 78; ID 13
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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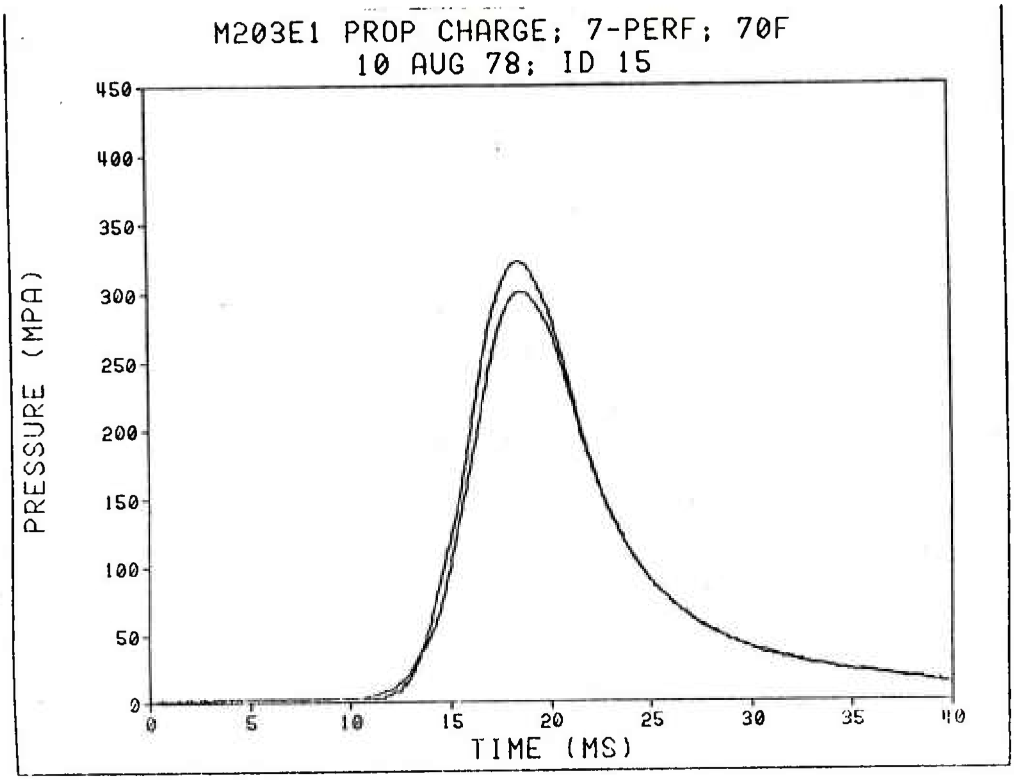
60
80
100
0
5
10
15
20
25
30
35
40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10 AUG 78; ID 15
PRESSURE (MPA)
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400
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300
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200
150
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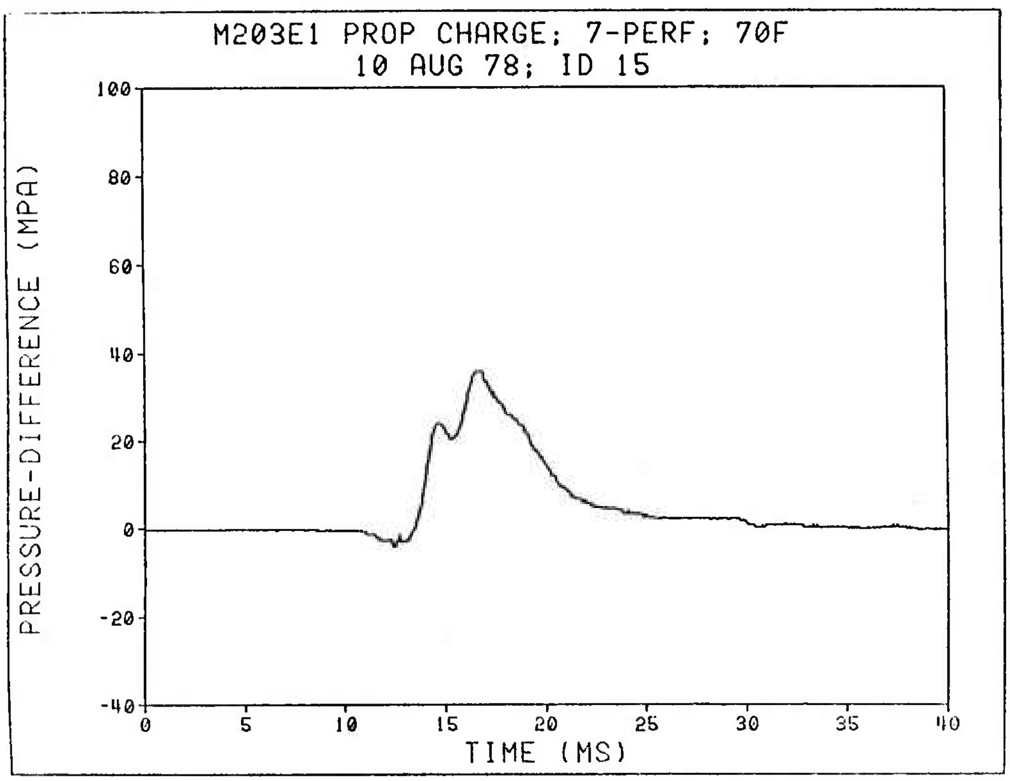
50
0
0
5
10
15
20
25
30
35
40
TIME (MS)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PRESSURE-DIFFERENCE (MPA)
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-40
0
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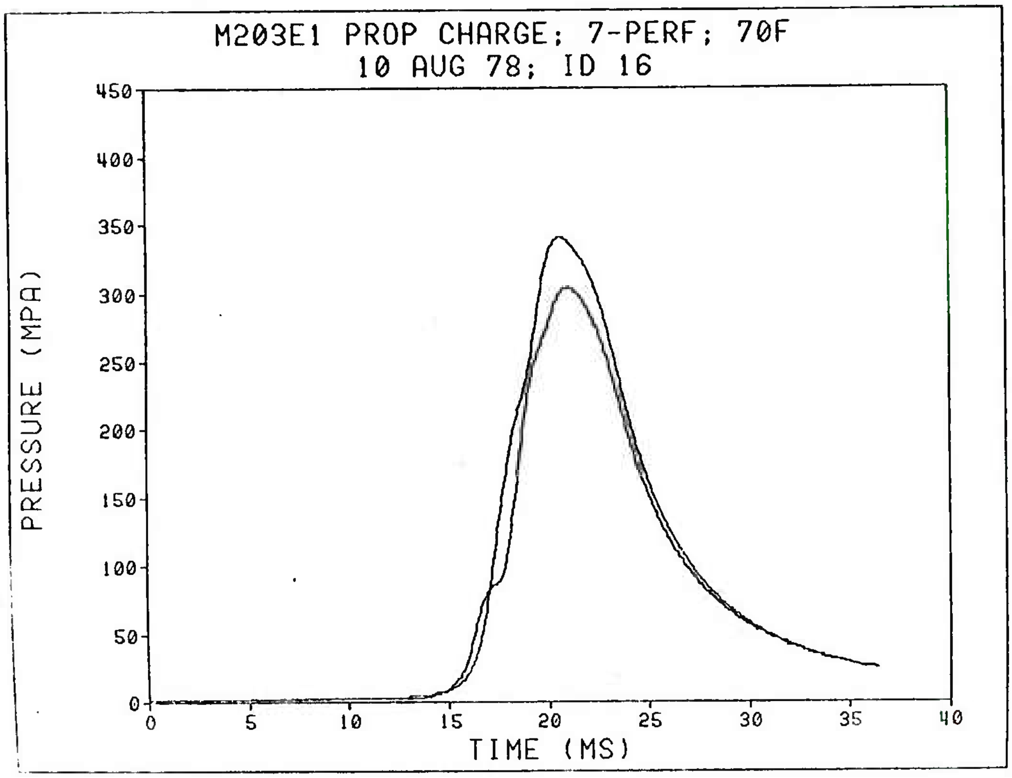
10
15
20
25
30
35
40
TIME (MS)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PRESSURE (MPA)
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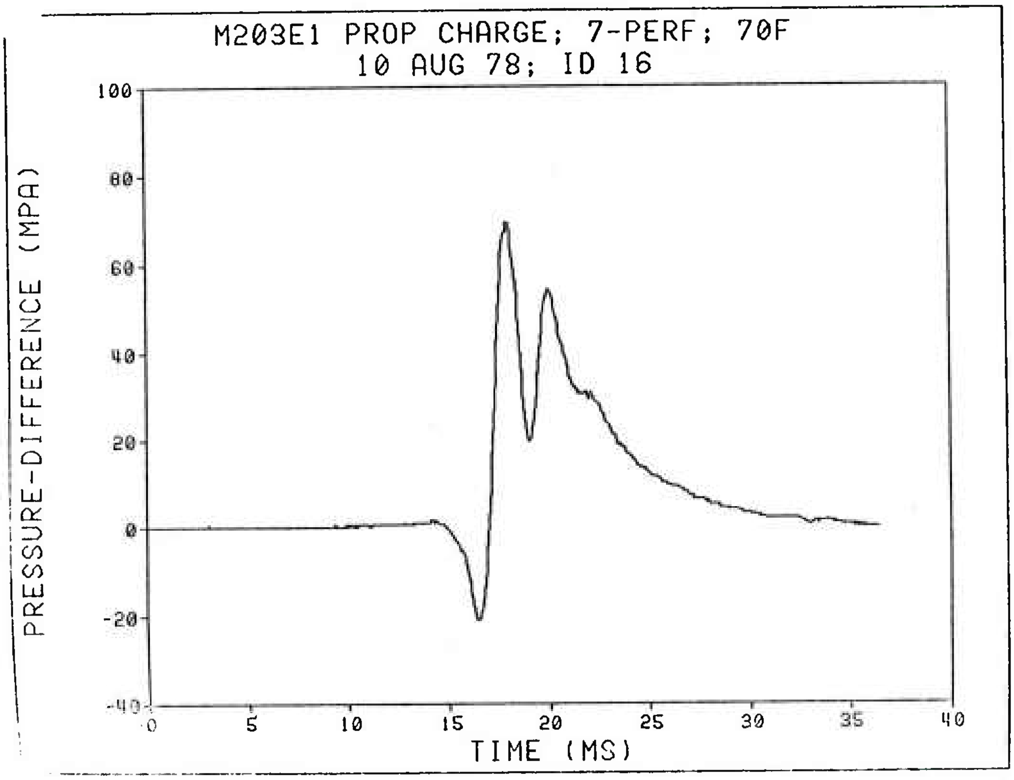
5
10
15
20
25
30
35
40
TIME (MS)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10 AUG 78; ID 16
PRESSURE-DIFFERENCE (MPA)
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80
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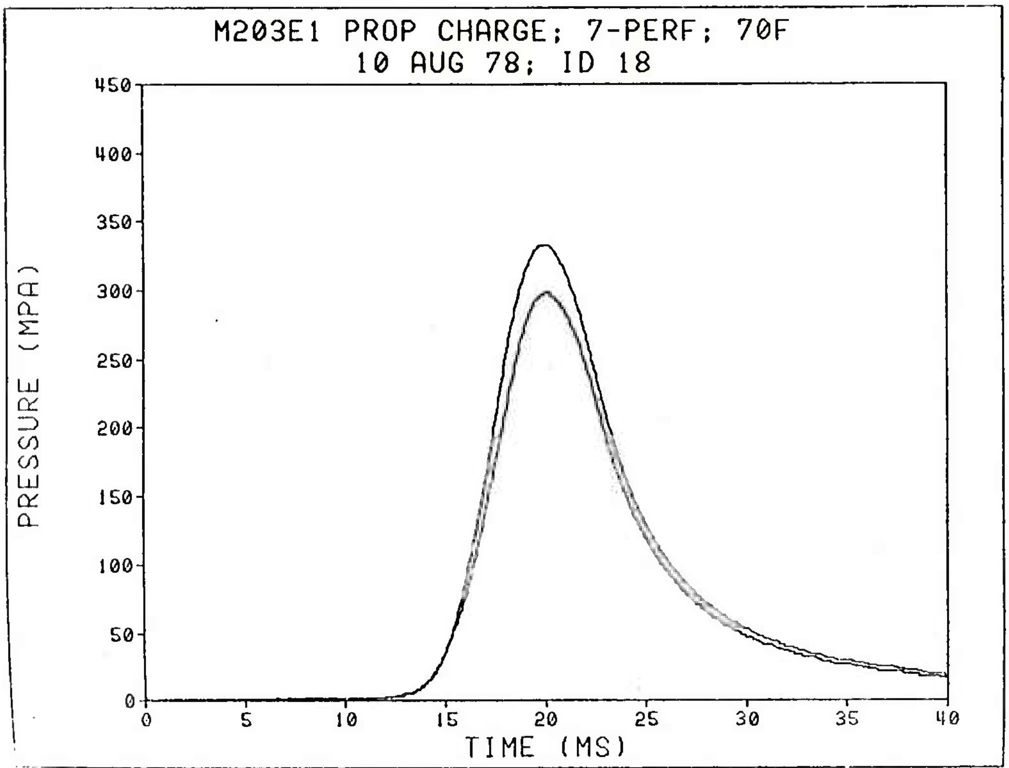
-40
0
5
10
15
20
25
30
35
40
TIME (MS)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PRESSURE (MPA)
TIME (MS)
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450
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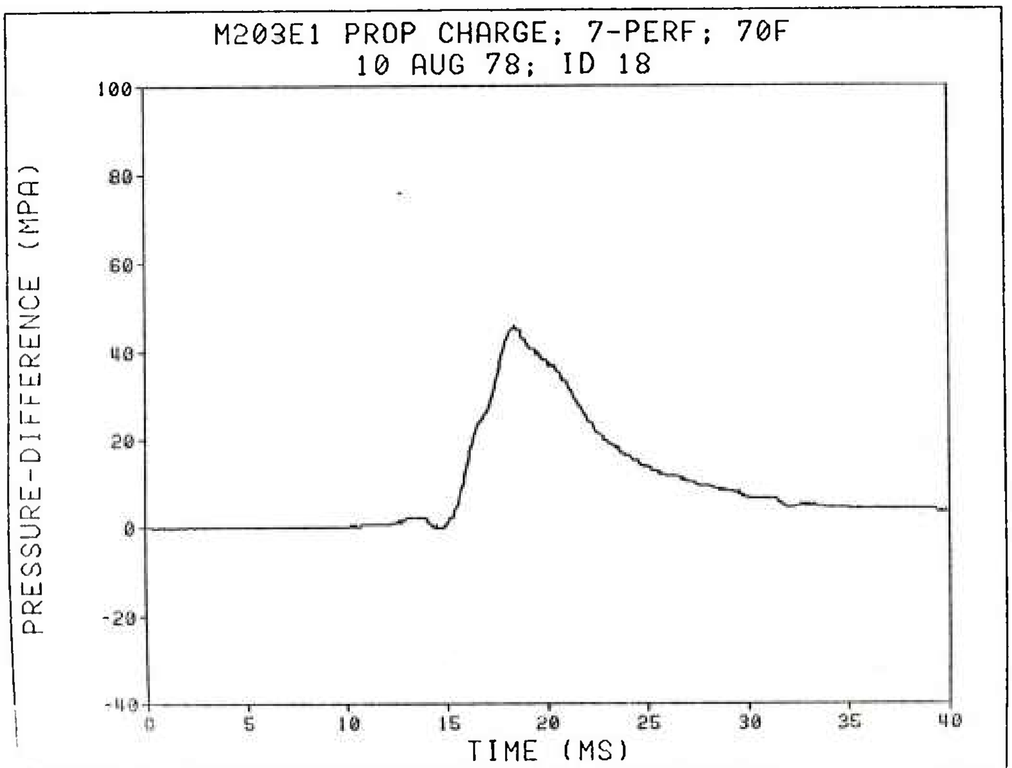
5
10
15
20
25
30
35
40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PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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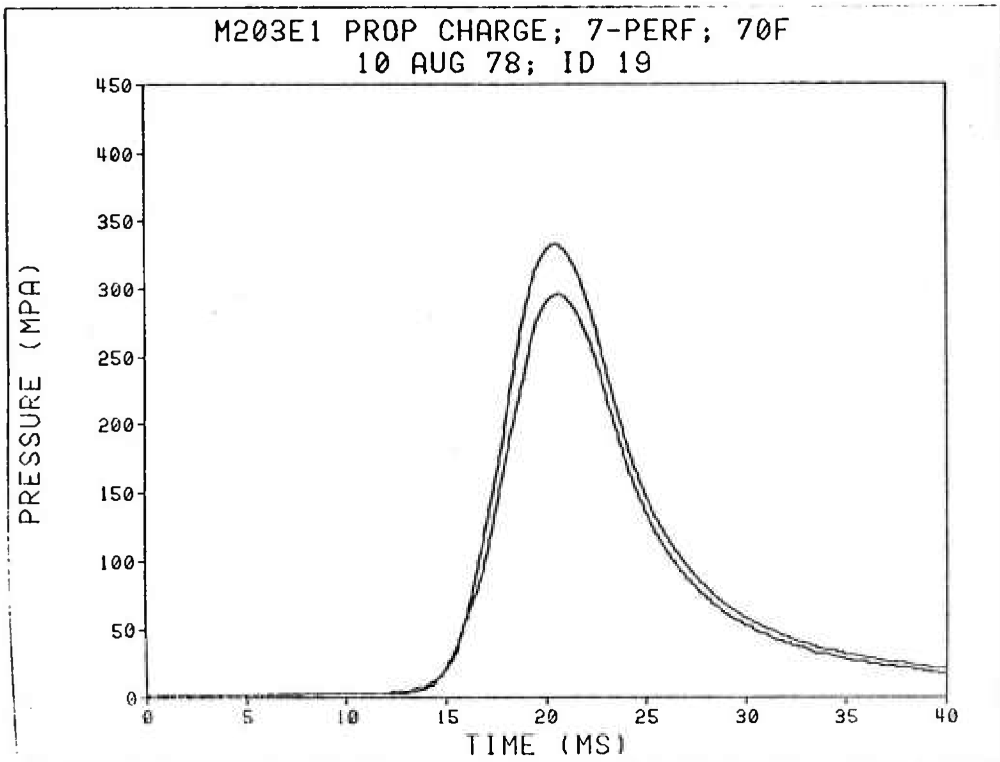
-20
0
20
40
60
80
100
0
5
10
15
20
25
30
35
40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PRESSURE (MPA)
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400
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300
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150
100
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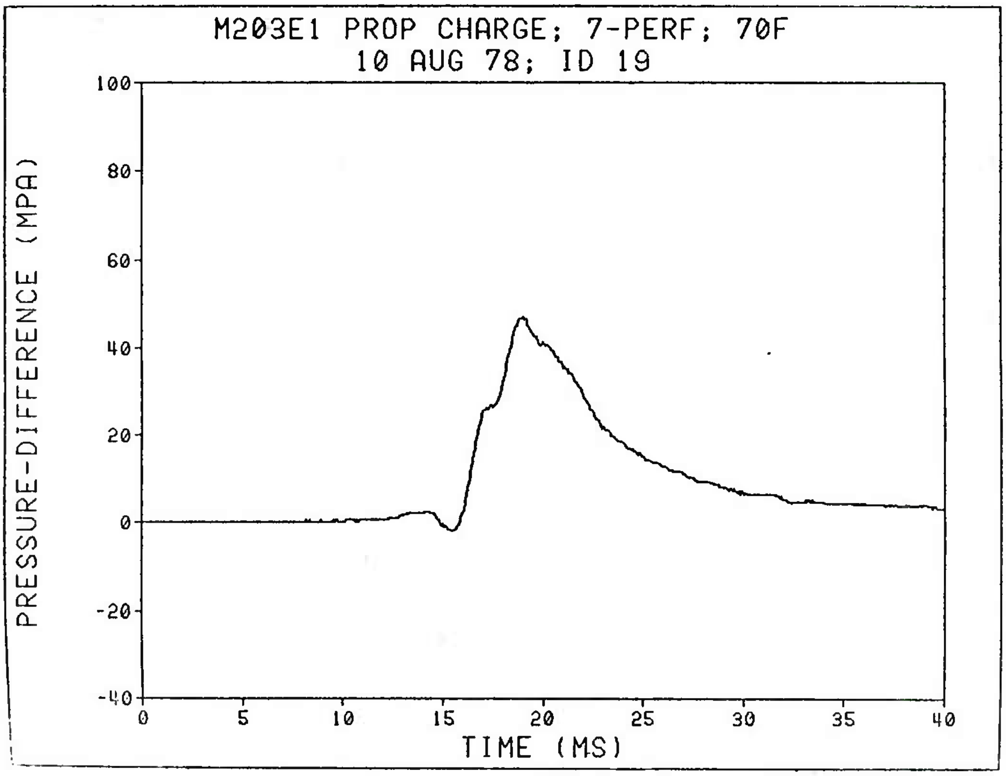
0
0
5
10
15
20
25
30
35
40
TIME (MS)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10 AUG 78; ID 19
PRESSURE-DIFFERENCE (MPA)
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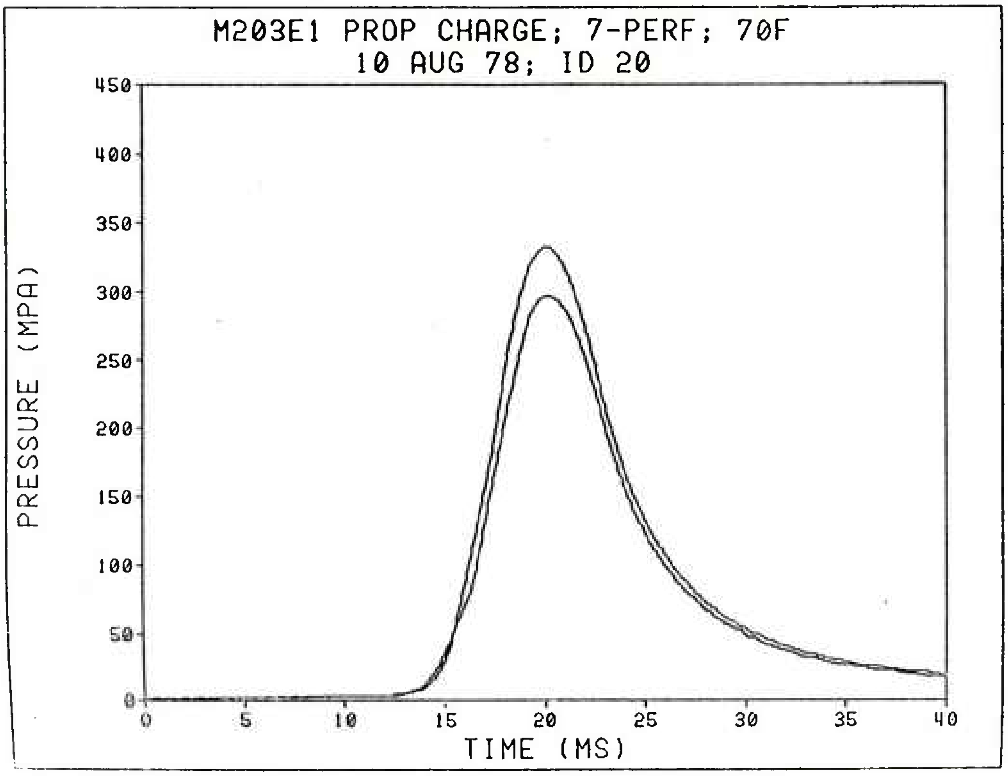
80
60
40
20
0
-20
-40
0
5
10
15
20
25
30
35
40
TIME (MS)



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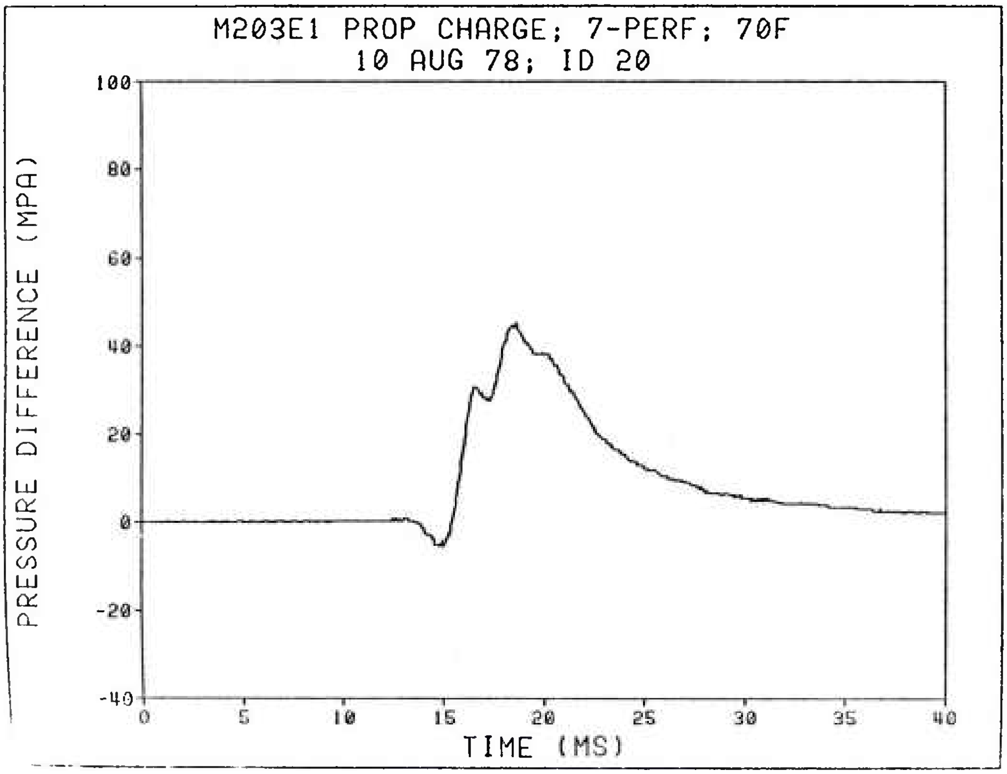
10 AUG 78; ID 20
PRESSURE (MPA)
450
400
350
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
TIME (MS)



M203E1 PROP CHARGE; 7-PERF; 70F
10 AUG 78; ID 20
PRESSURE DIFFERENCE (MPA)
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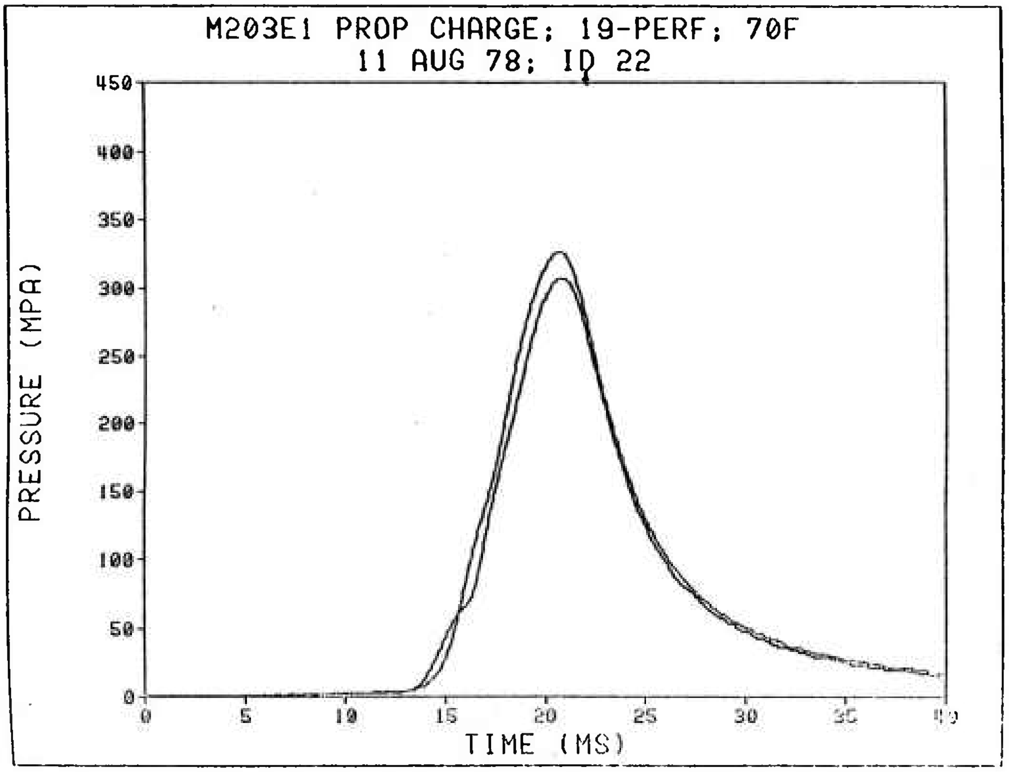
80
60
40
20
0
-20
-40
0
5
10
15
20
25
30
35
40
TIME (MS)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11 AUG 78; ID 22
PRESSURE (MPA)
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150
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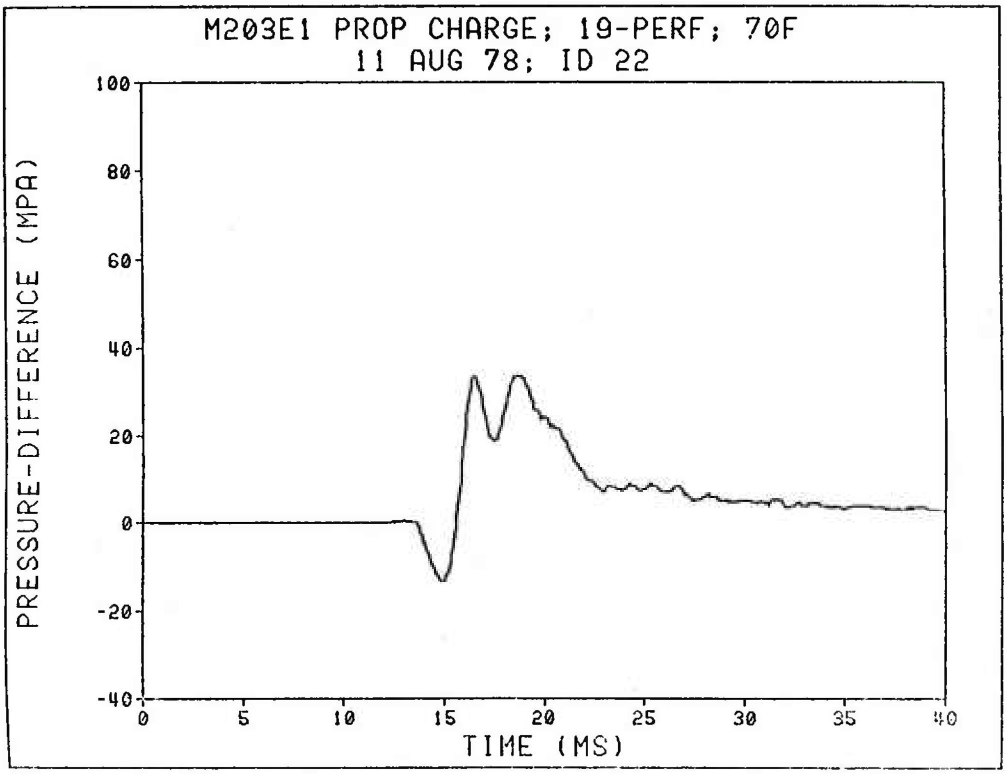
50
0
0
5
10
15
20
25
30
35
40
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 22
PRESSURE-DIFFERENCE (MPA)
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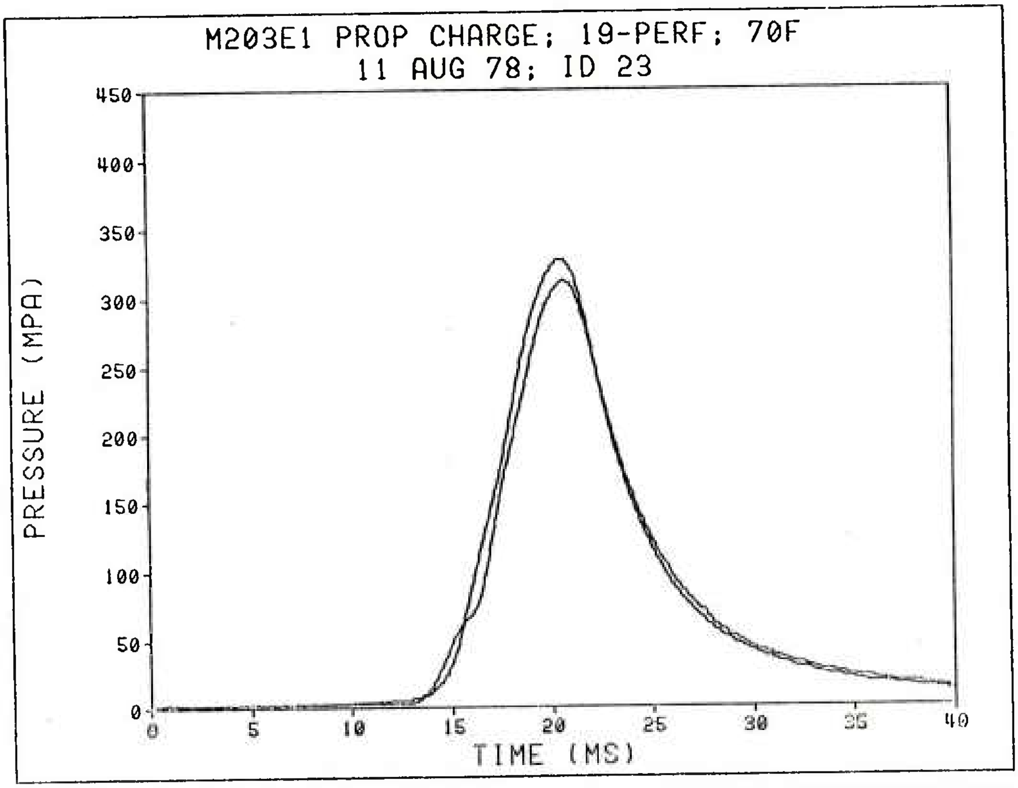
40
20
0
-20
-40
0
5
10
15
20
25
30
35
40
TIME (MS)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11 AUG 78; ID 23
PRESSURE (MPA)
TIME (MS)
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350
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450
0
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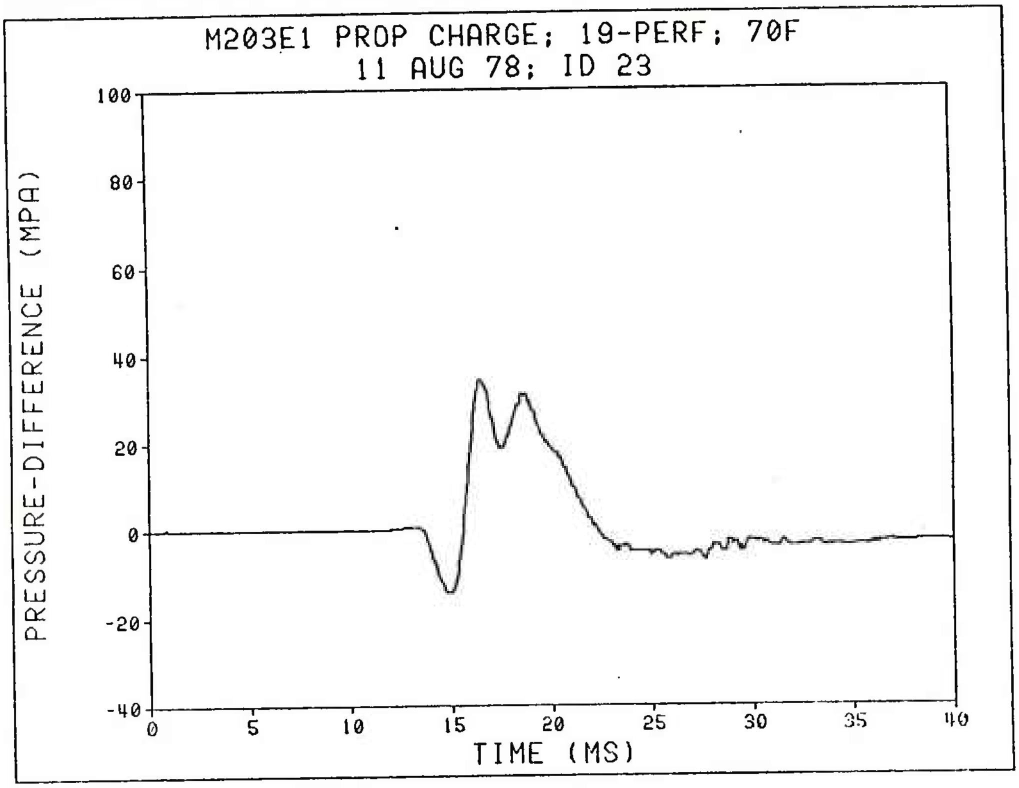
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11 AUG 78; ID 23
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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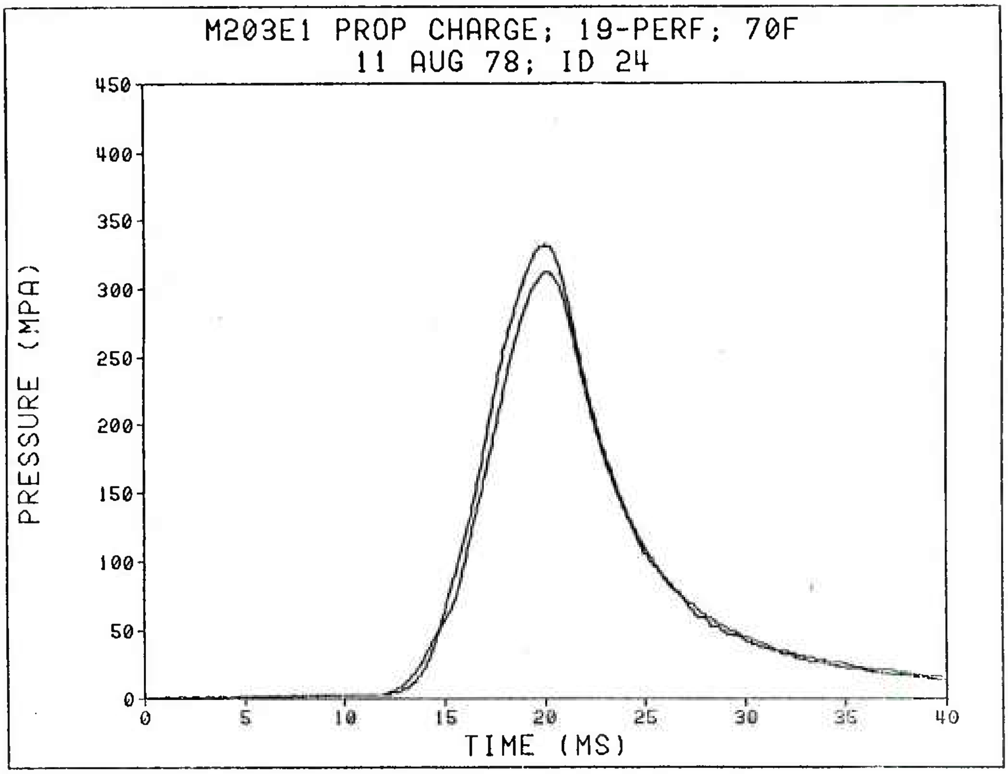
M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 24
PRESSURE (MPA)
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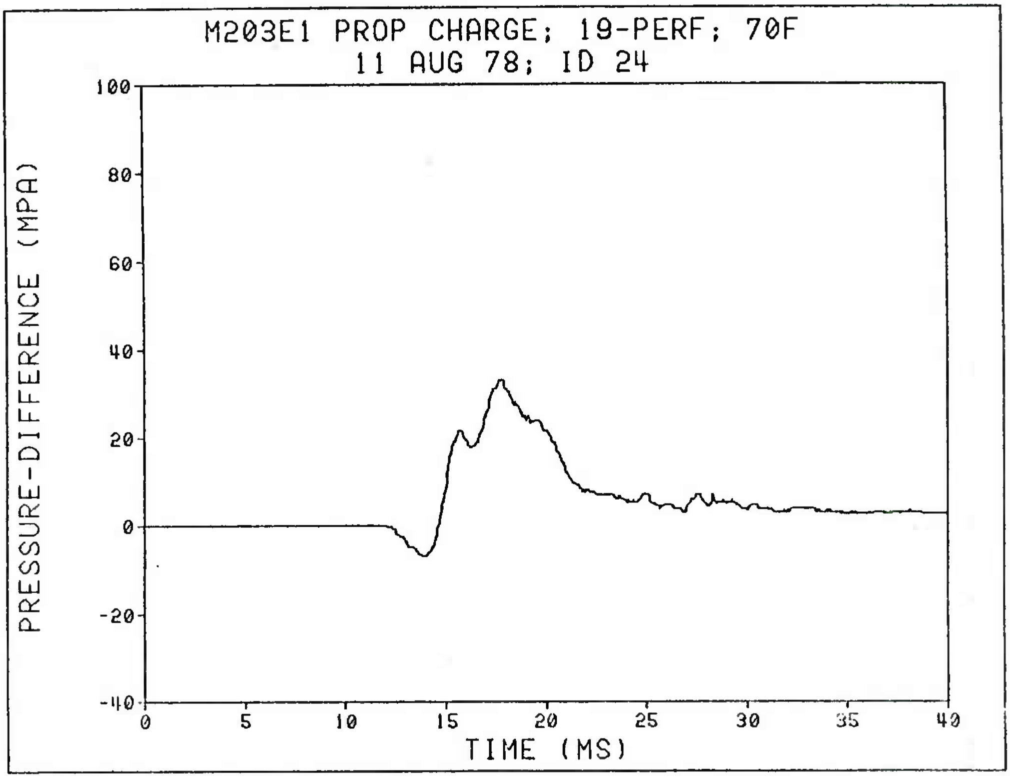
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 24
PRESSURE-DIFFERENCE (MPA)
100
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-20
-40
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25
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35
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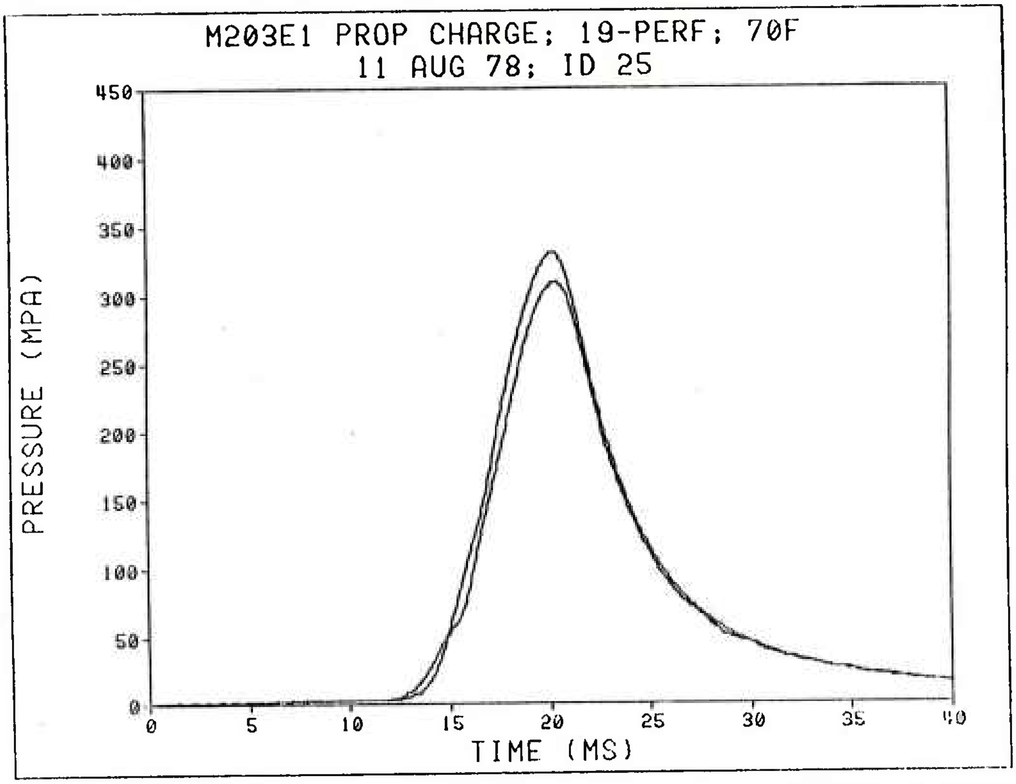
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 25
PRESSURE (MPA)
TIME (MS)
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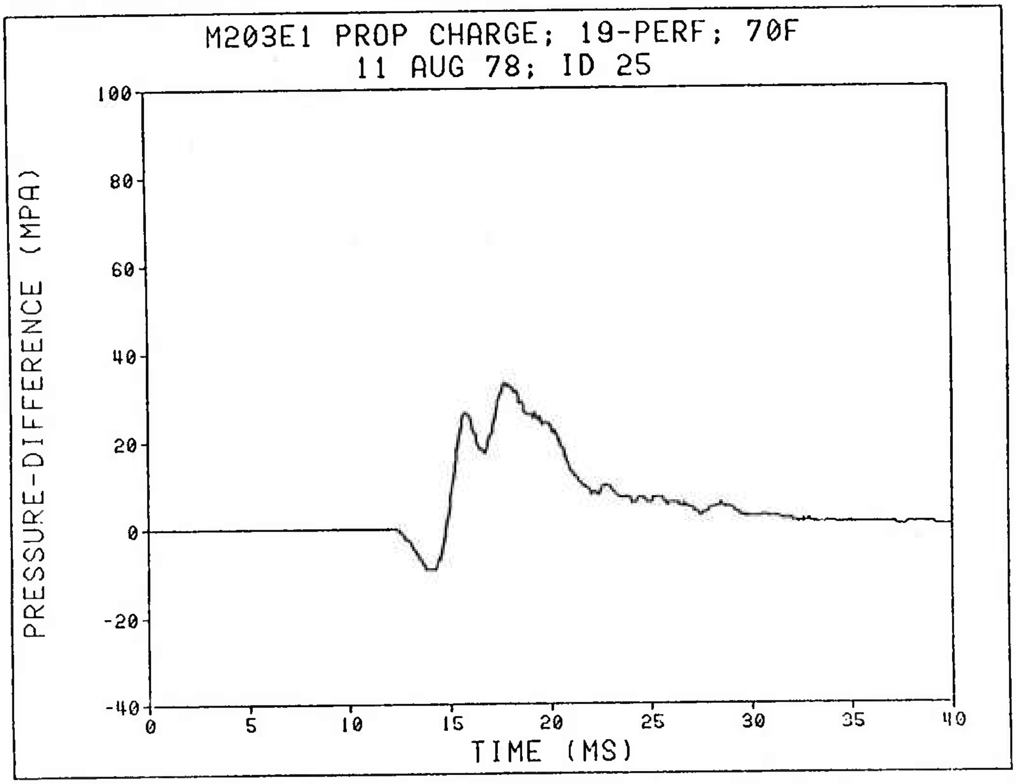
M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 25
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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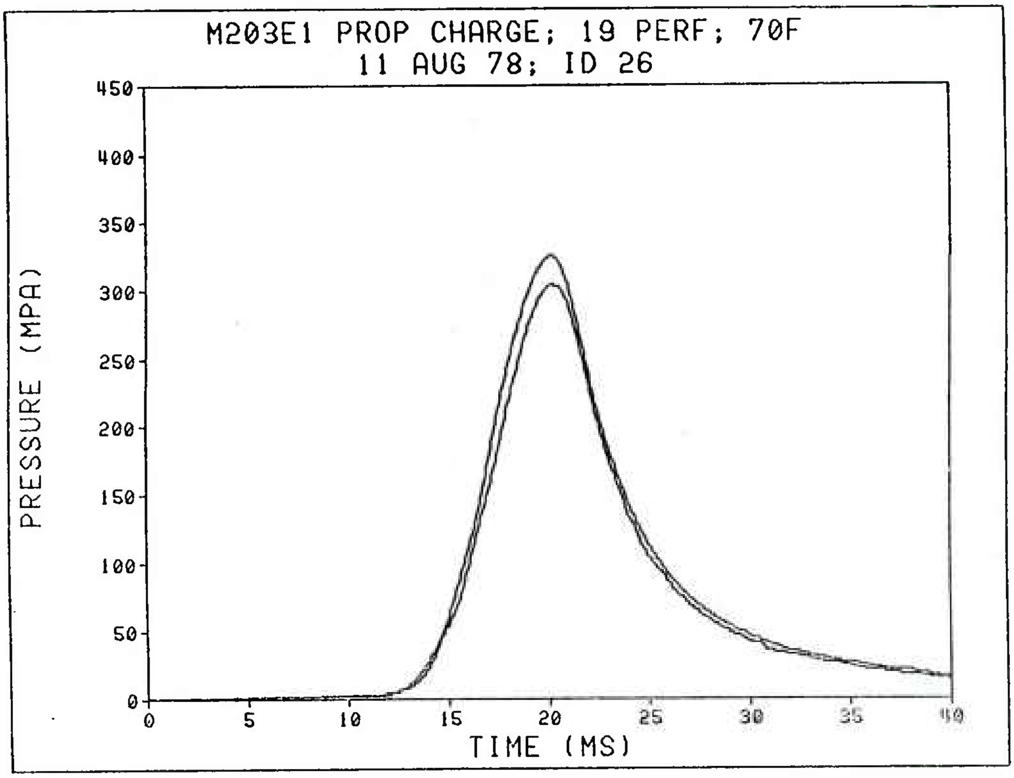
M203E1 PROP CHARGE; 19 PERF; 70F
11 AUG 78; ID 26
PRESSURE (MPA)
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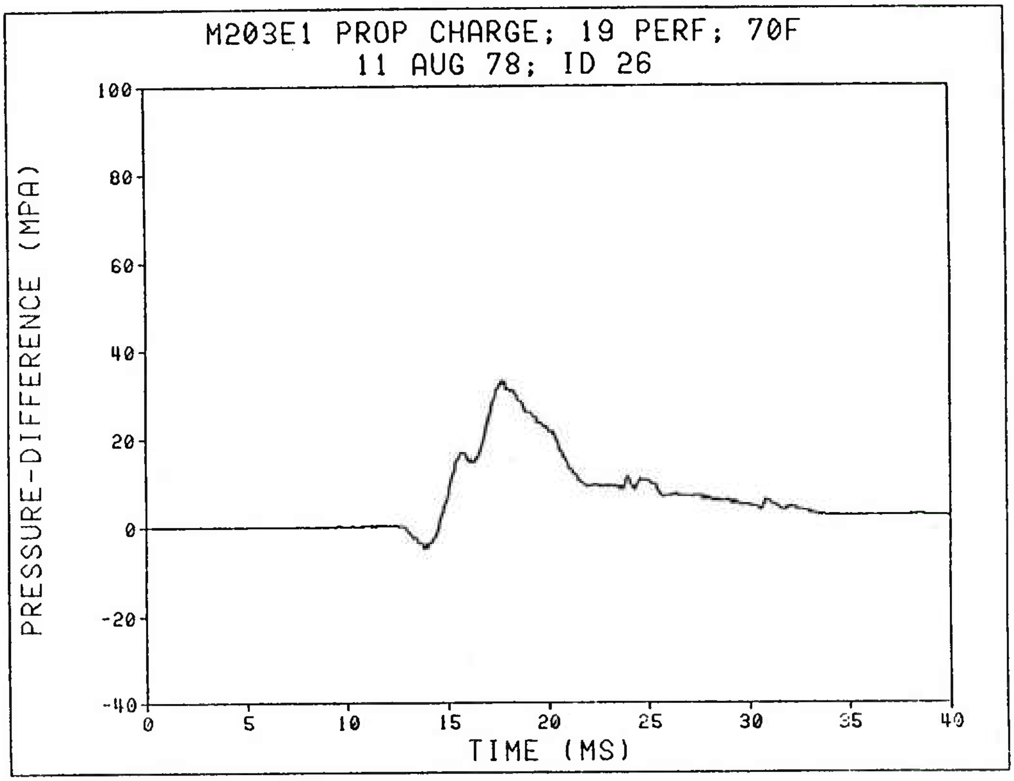
M203E1 PROP CHARGE; 19 PERF; 70F
11 AUG 78; ID 26
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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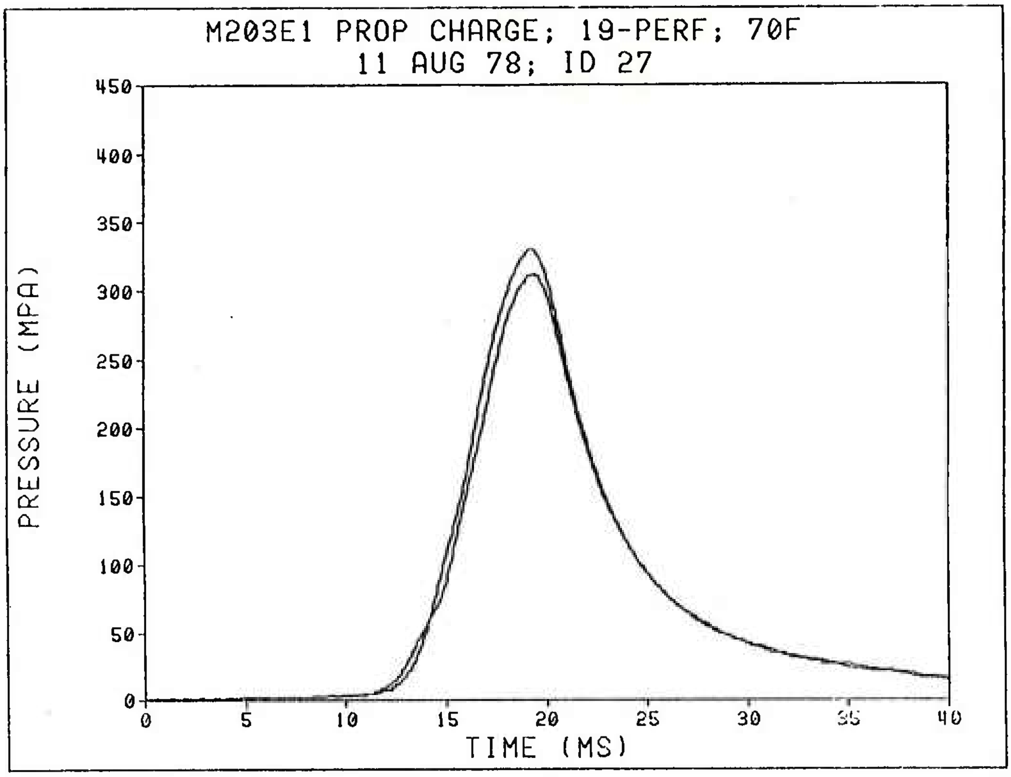
M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 27
PRESSURE (MPA)
TIME (MS)
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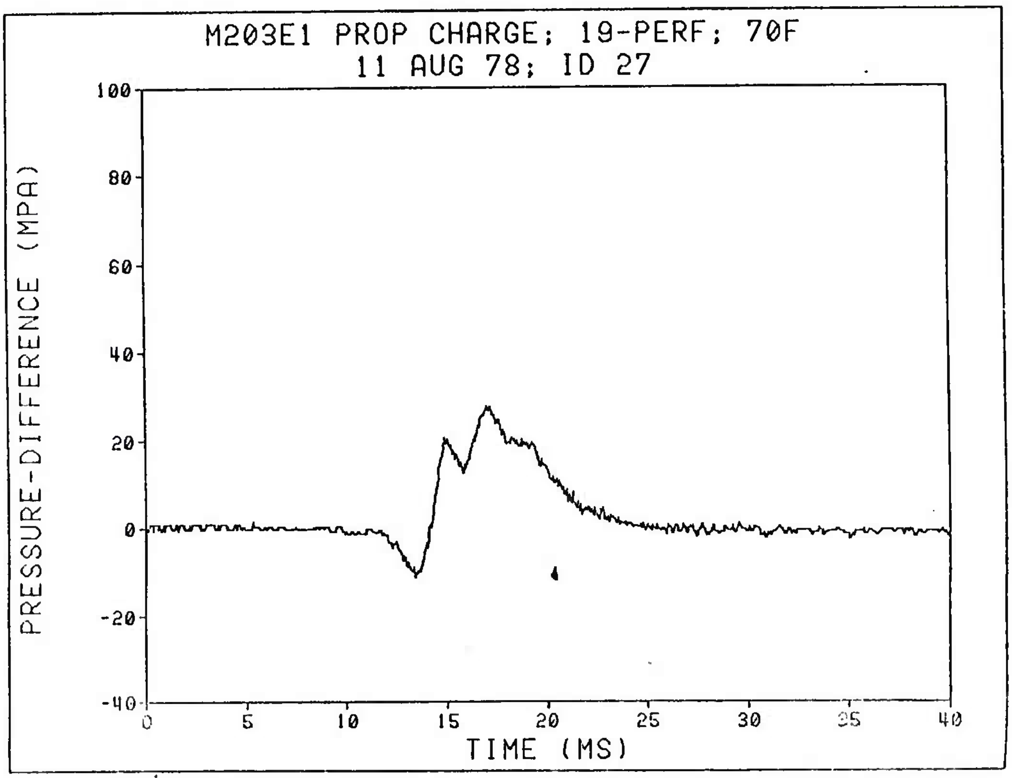
M203E1 PROP CHARGE; 19-PERF; 70F
11 AUG 78; ID 27
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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-20
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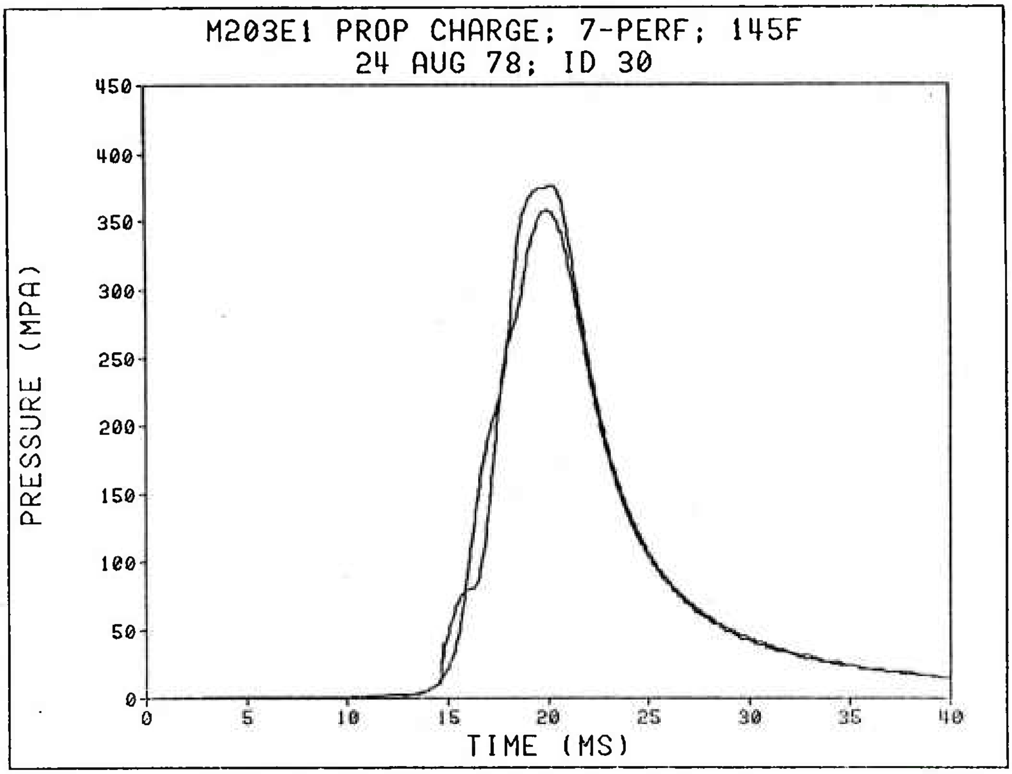
M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 30
PRESSURE (MPA)
TIME (MS)
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200
250
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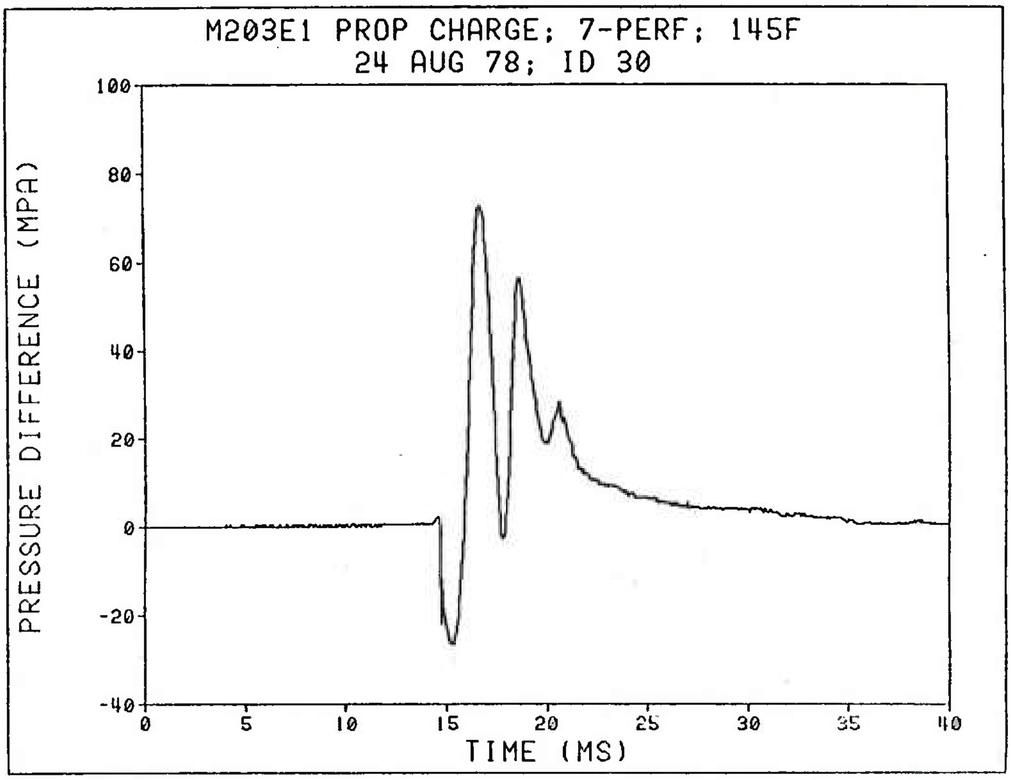
M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 30
PRESSURE DIFFERENCE (MPA)
TIME (MS)
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-20
0
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40
60
80
100
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5
10
15
20
25
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35
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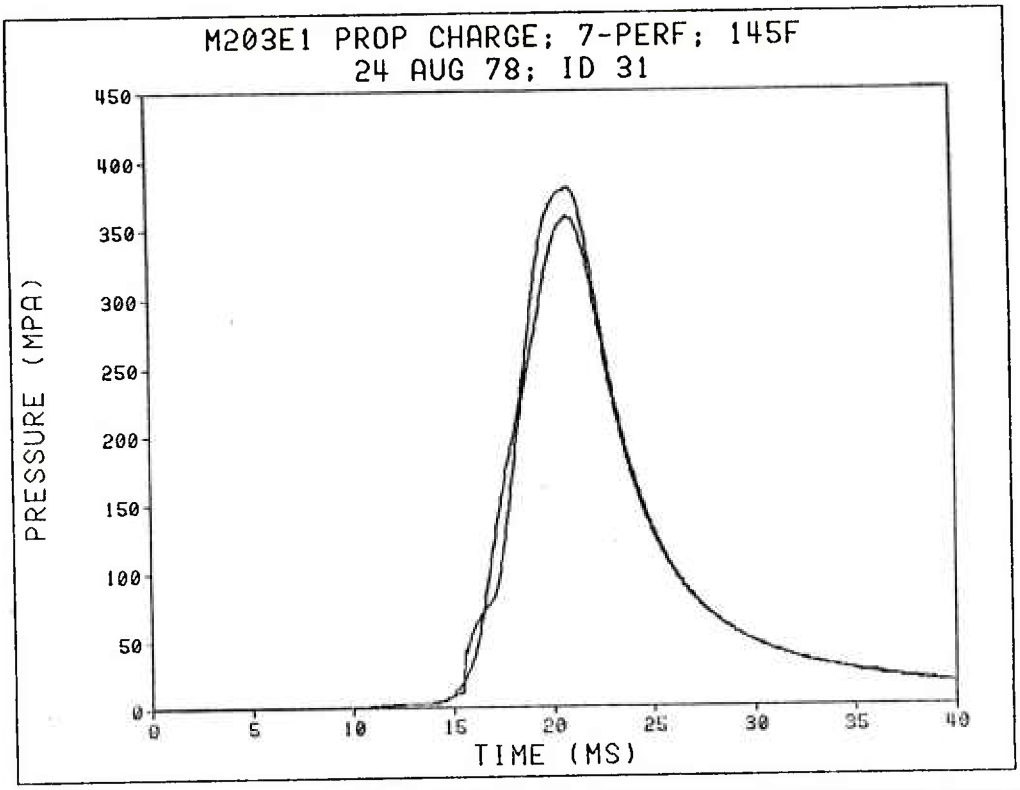
M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 31
PRESSURE (MPA)
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400
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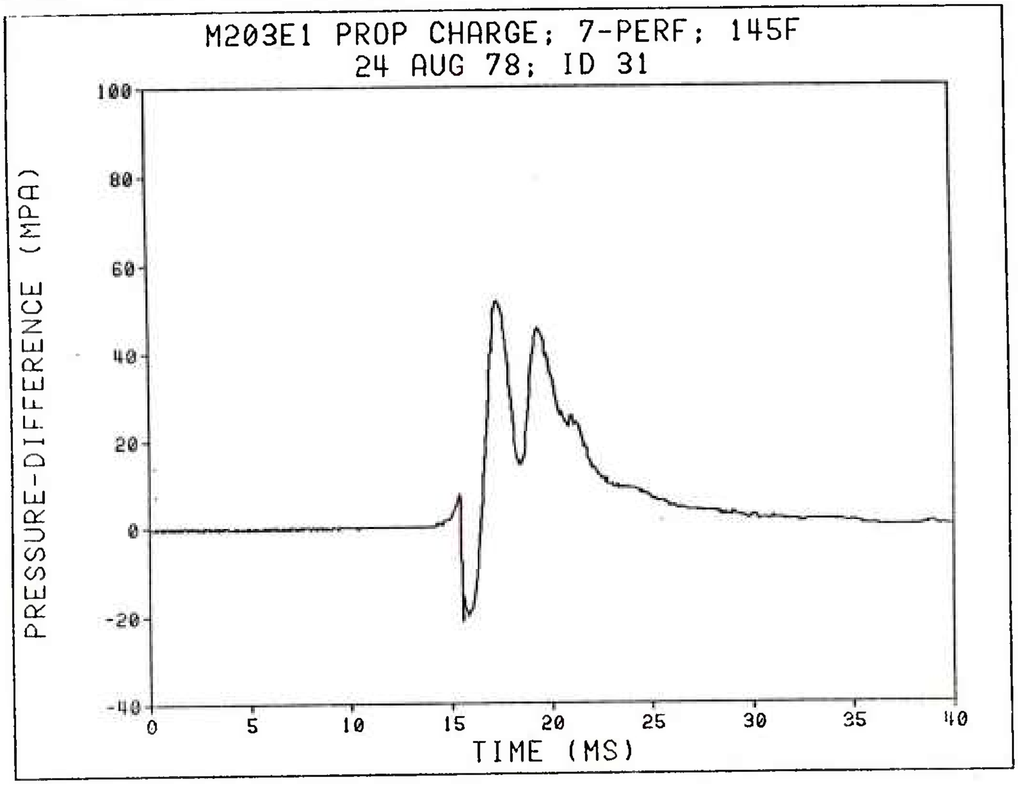
300
250
200
150
100
50
0
0
5
10
15
20
25
30
35
40
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 31
PRESSURE-DIFFERENCE (MPA)
100
80
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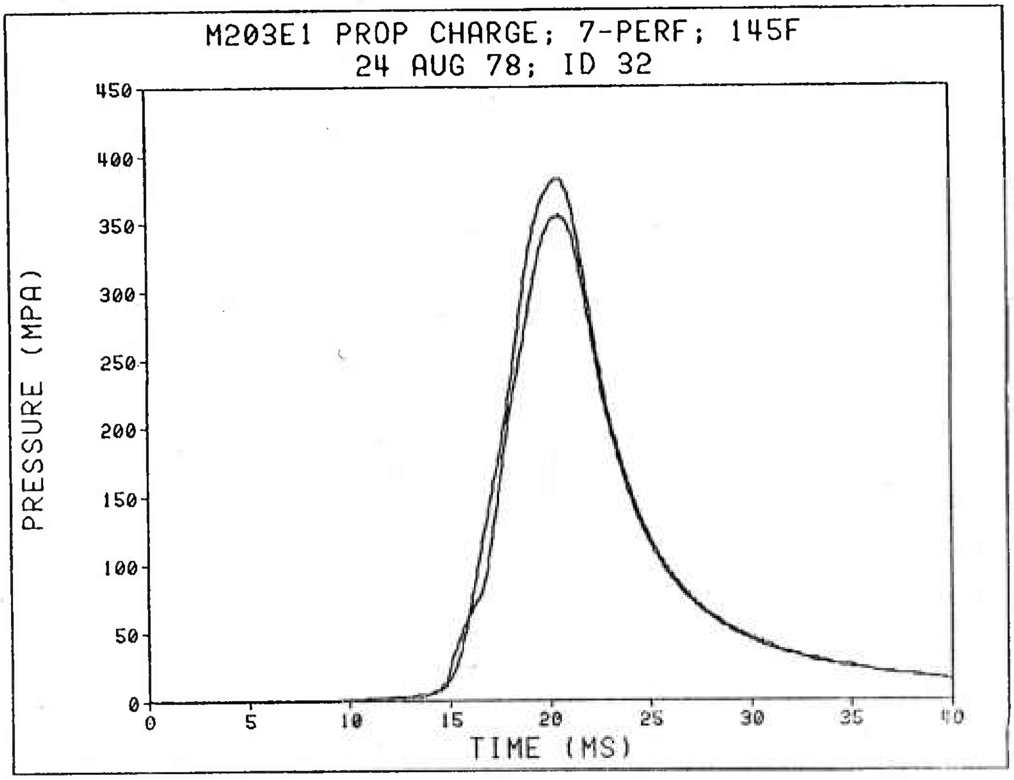
40
20
0
-20
-40
0
5
10
15
20
25
30
35
40
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 32
PRESSURE (MPA)
TIME (MS)
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150
100
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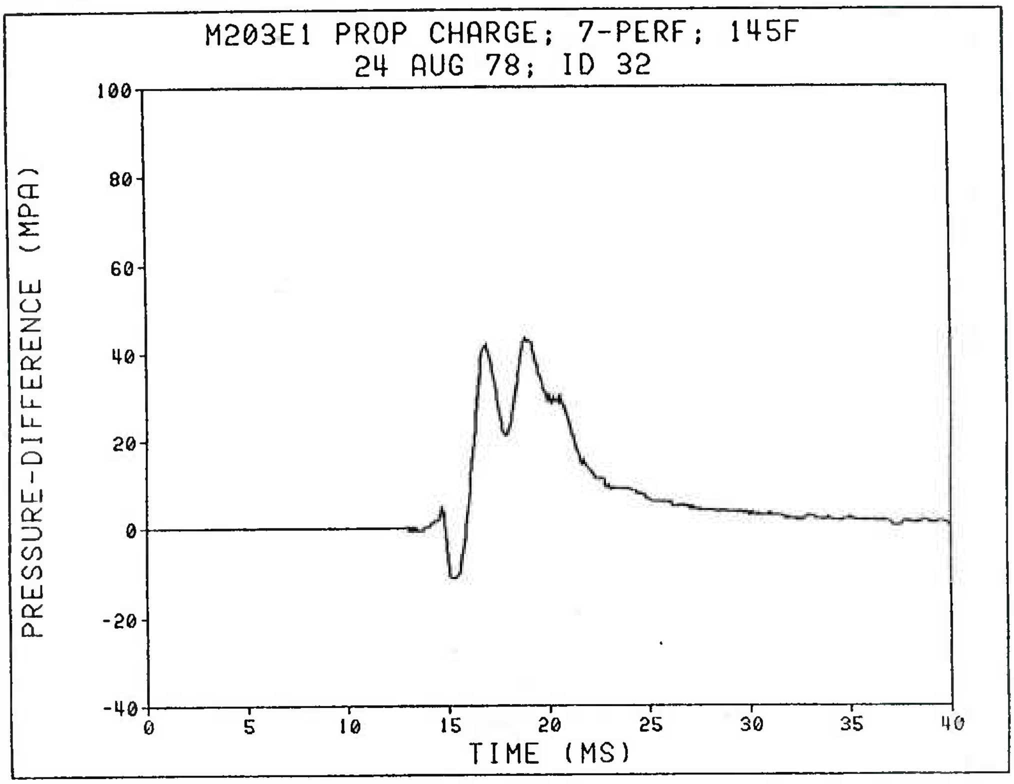
M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 32
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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40
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-20
-40
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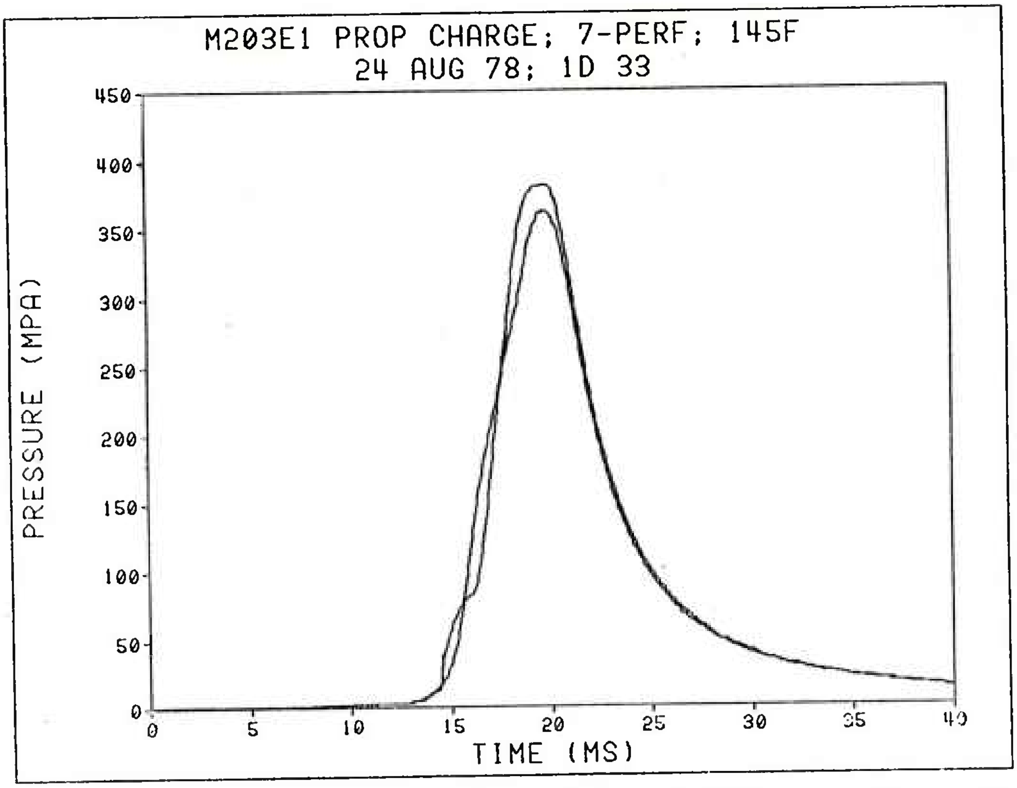
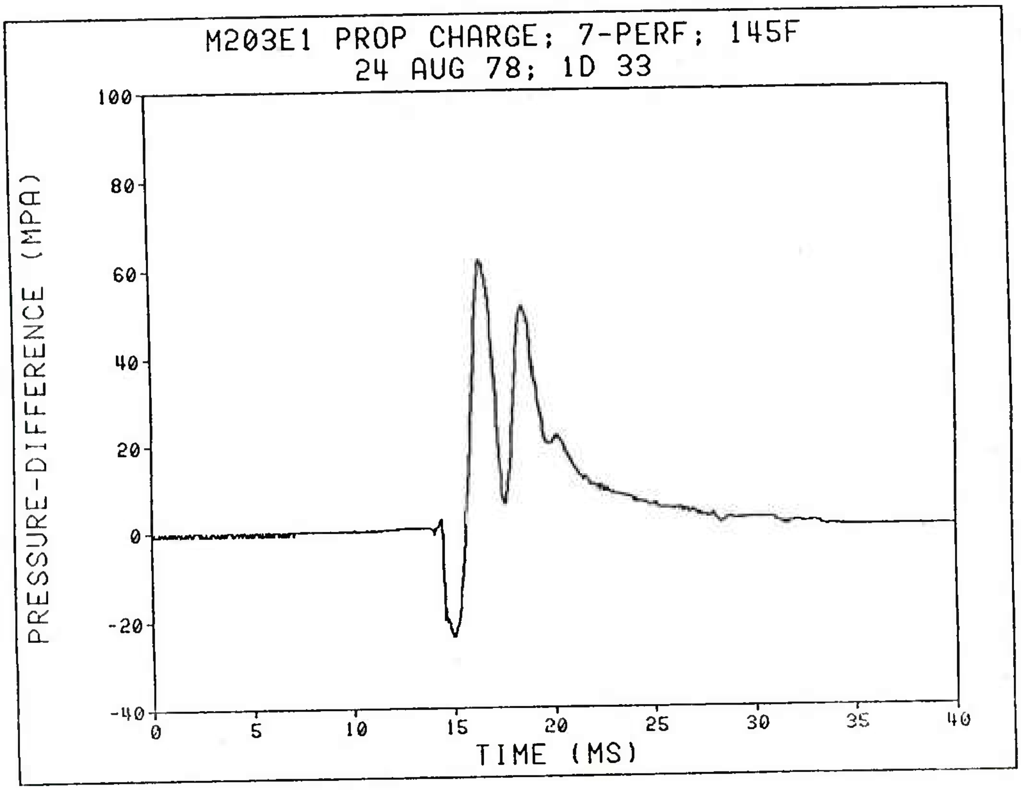
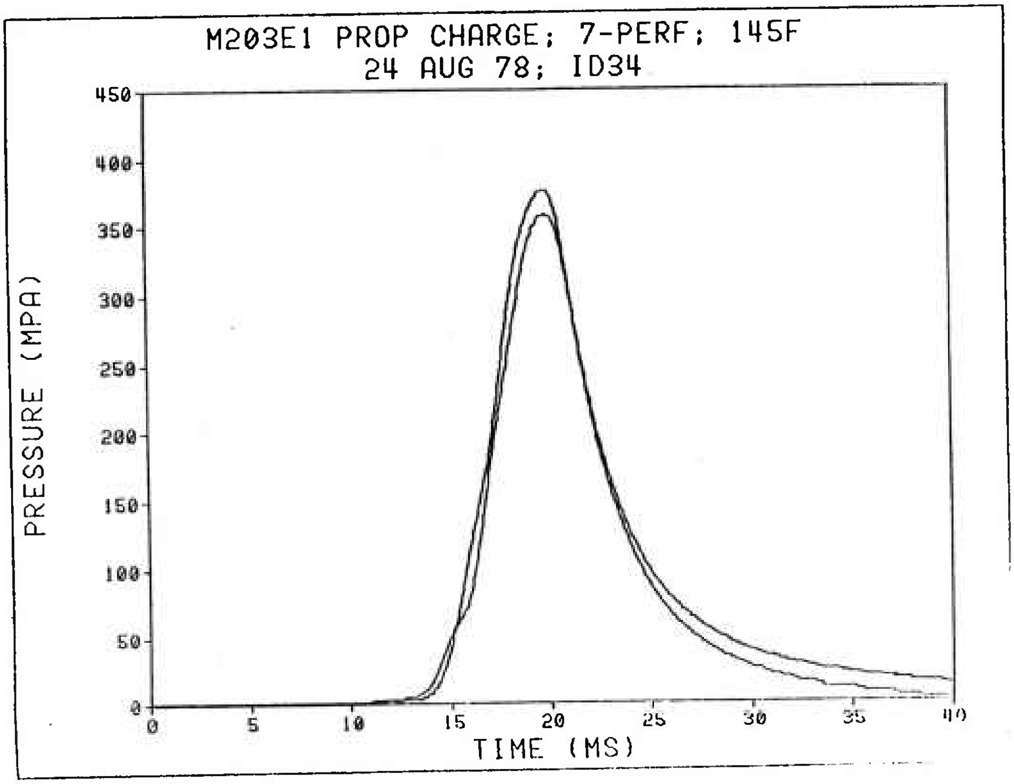

M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; 1D 33
PRESSURE (MPA)
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; 1D 33
PRESSURE-DIFFERENCE (MPA)
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID34
PRESSURE (MPA)
TIME (MS)
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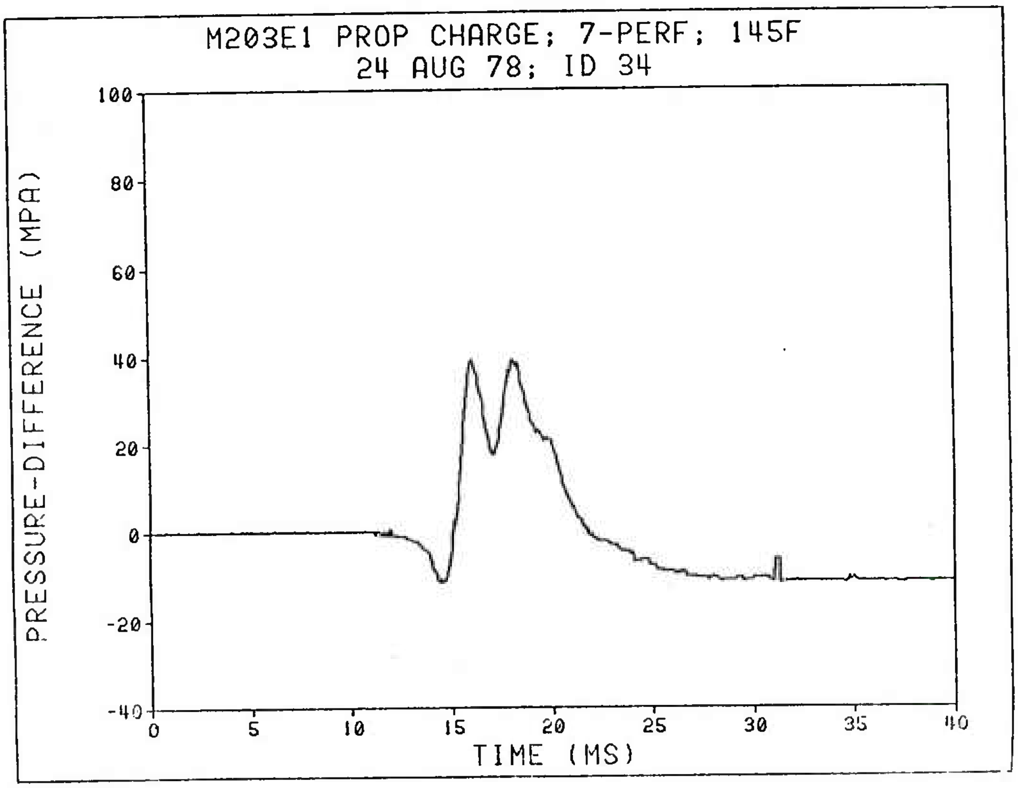
15
20
25
30
35
40
0
50
100
150
200
250
300
350
400
450


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 34
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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10
15
20
25
30
35
40
-40
-20
0
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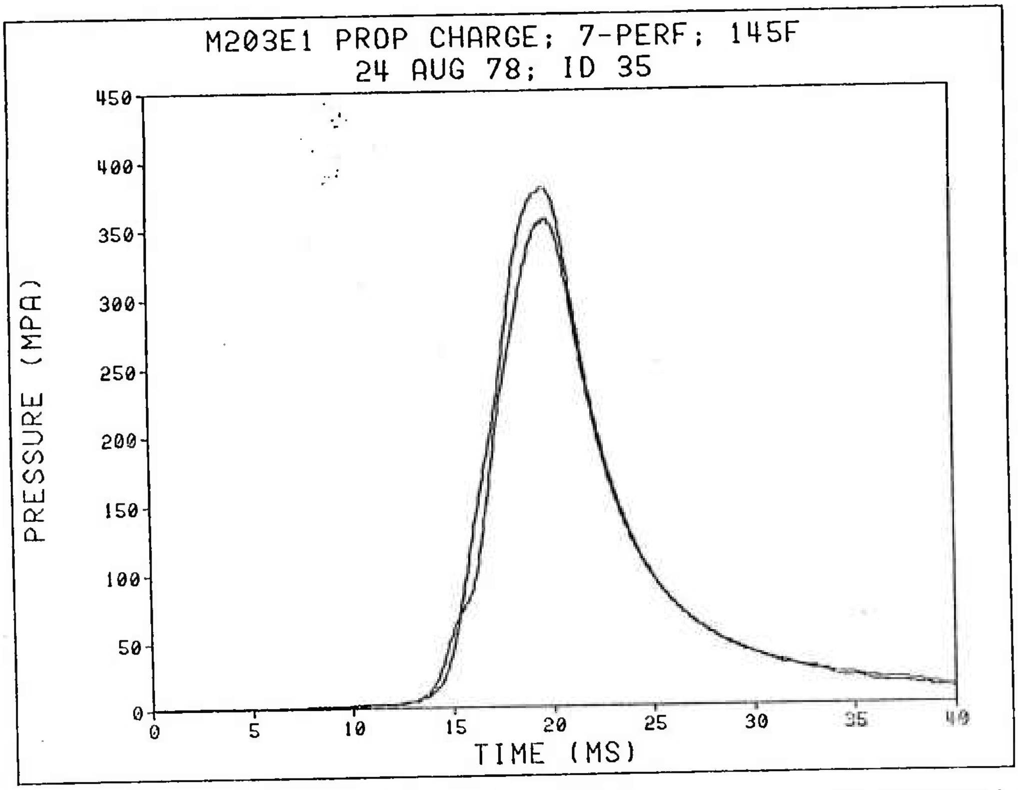
40
60
80
100


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 35
PRESSURE (MPA)
TIME (MS)
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300
250
200
150
100
50
0
0
5
10
15
20
25
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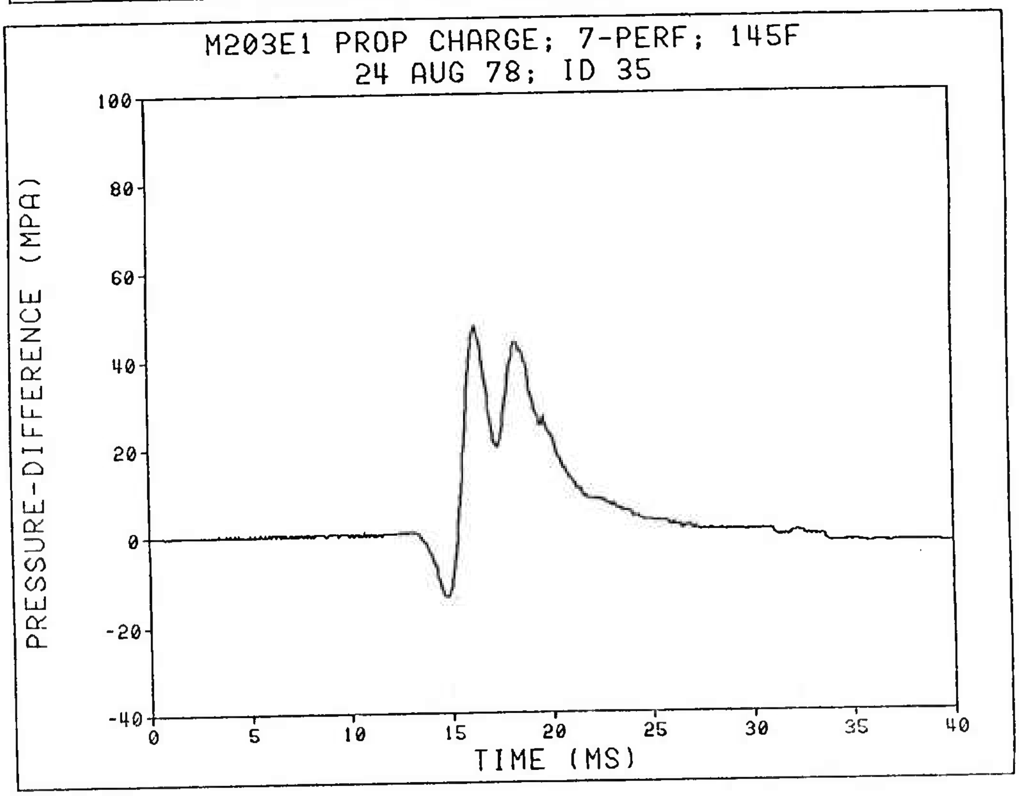
35
40


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 35
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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60
40
20
0
-20
-40
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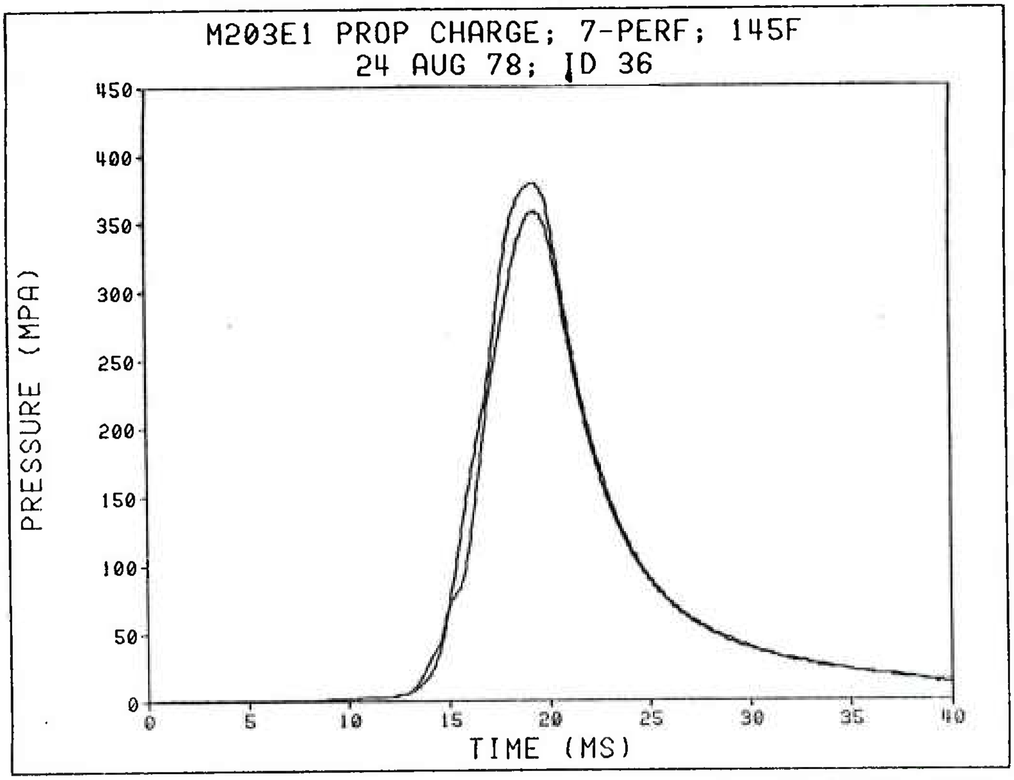
10
15
20
25
30
35
40


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 36
PRESSURE (MPA)
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200
150
100
50
0
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15
20
25
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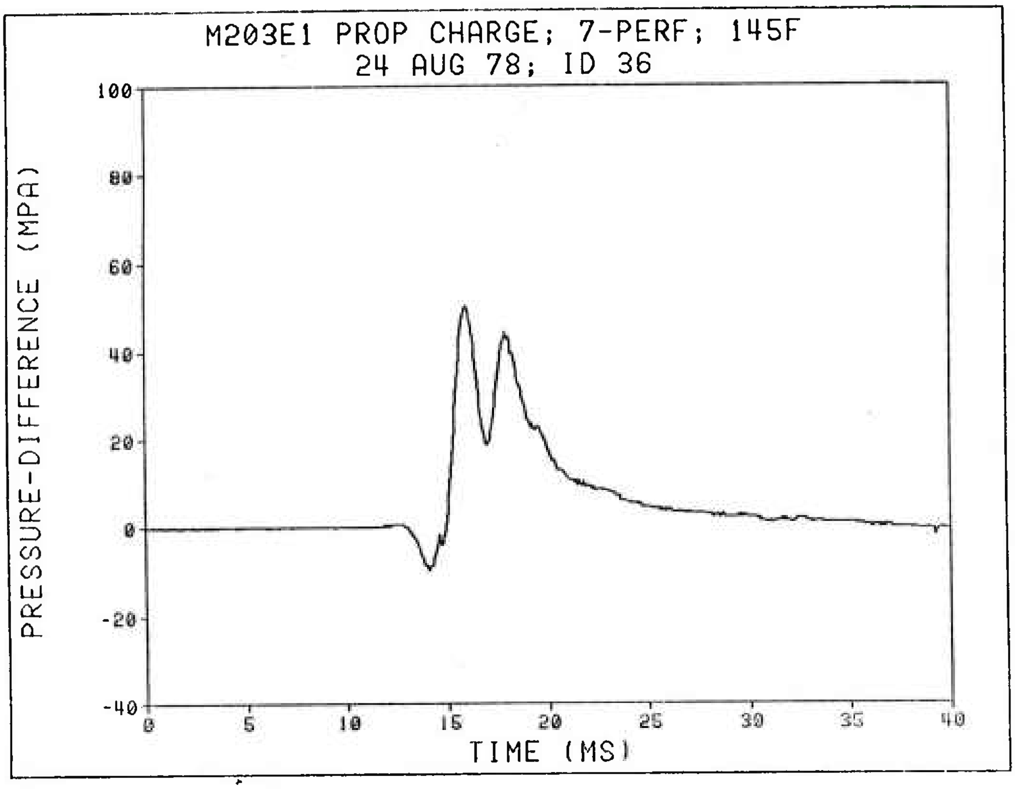
35
40
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; 145F
24 AUG 78; ID 36
PRESSURE-DIFFERENCE (MPA)
100
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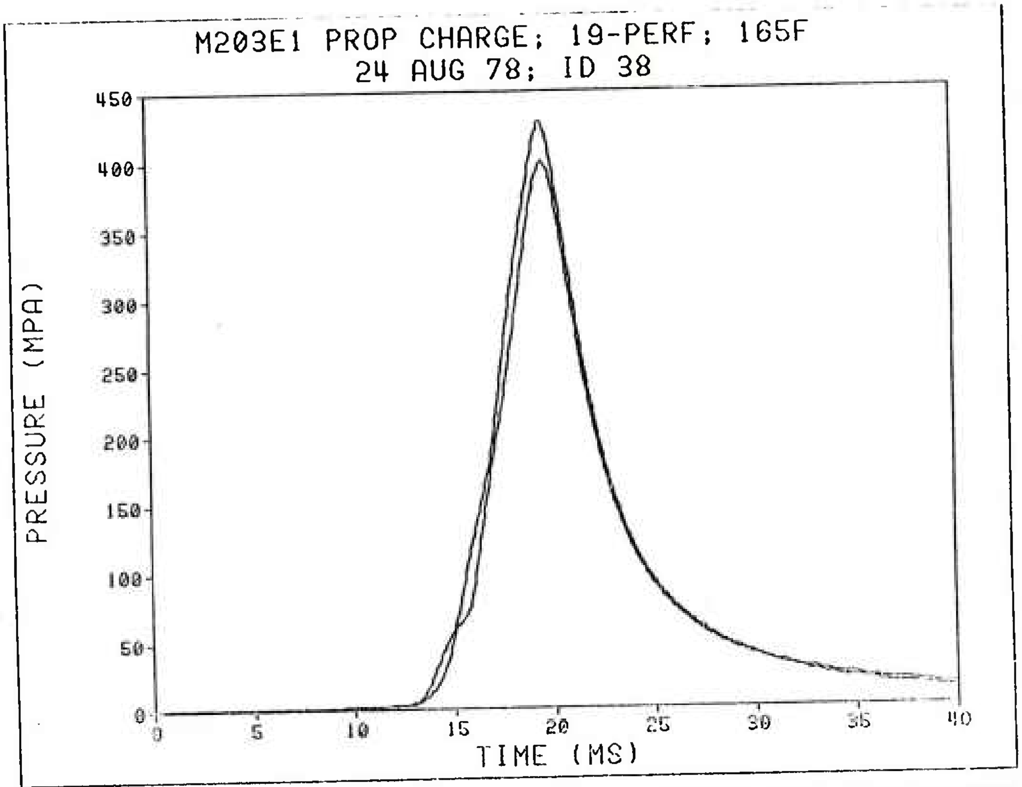
20
0
-20
-40
0
5
10
15
20
25
30
35
40
TIME (MS)



M203E1 PROP CHARGE; 19-PERF; 165F
24 AUG 78; ID 38
PRESSURE (MPA)
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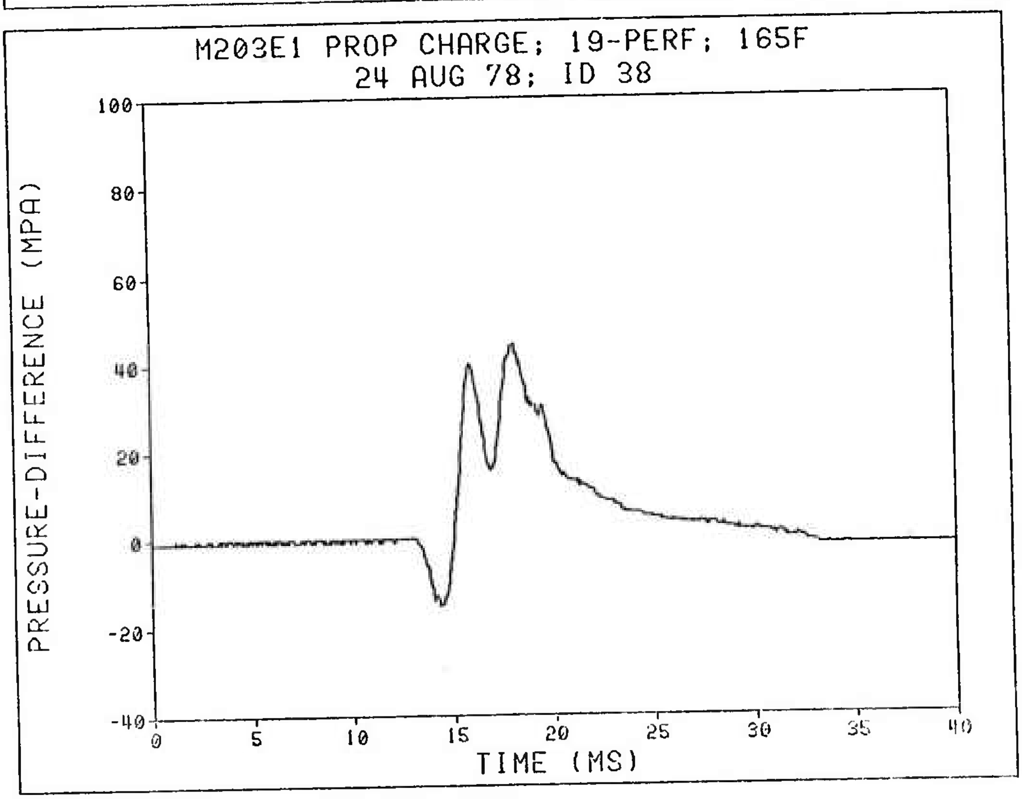
250
300
350
400
450
0
5
10
15
20
25
30
35
40
TIME (MS)



M203E1 PROP CHARGE; 19-PERF; 165F
24 AUG 78; ID 38
PRESSURE-DIFFERENCE (MPA)
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20
40
60
80
100
0
5
10
15
20
25
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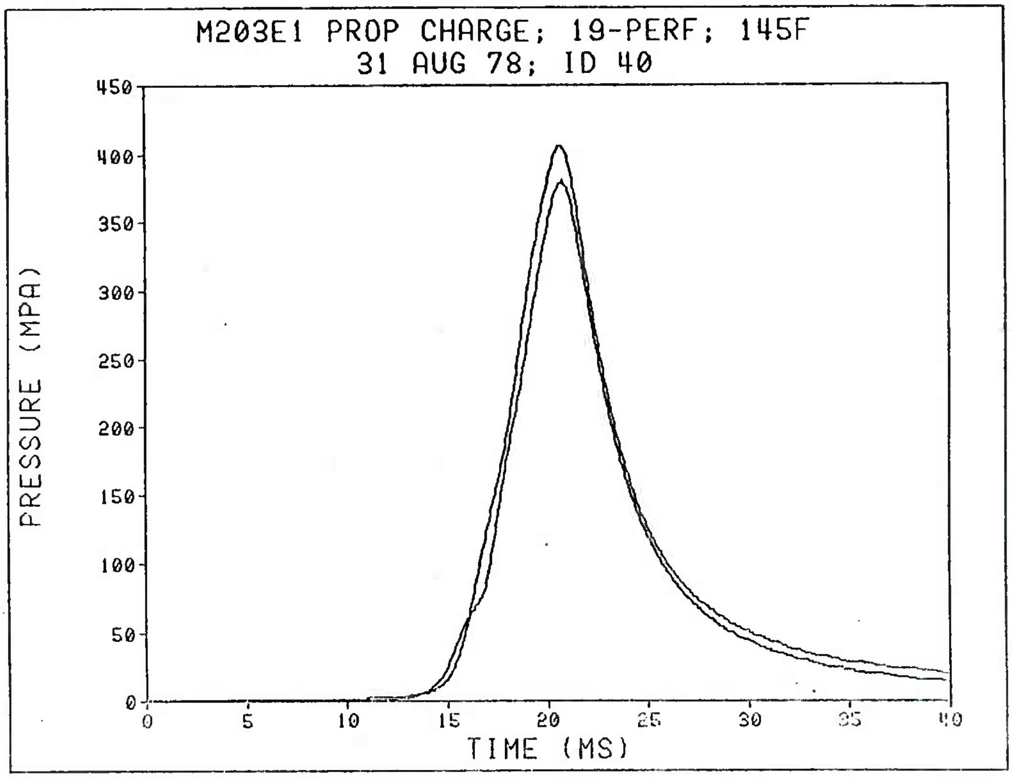
35
40
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 40
PRESSURE (MPA)
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350
300
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200
150
100
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0
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15
20
25
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35
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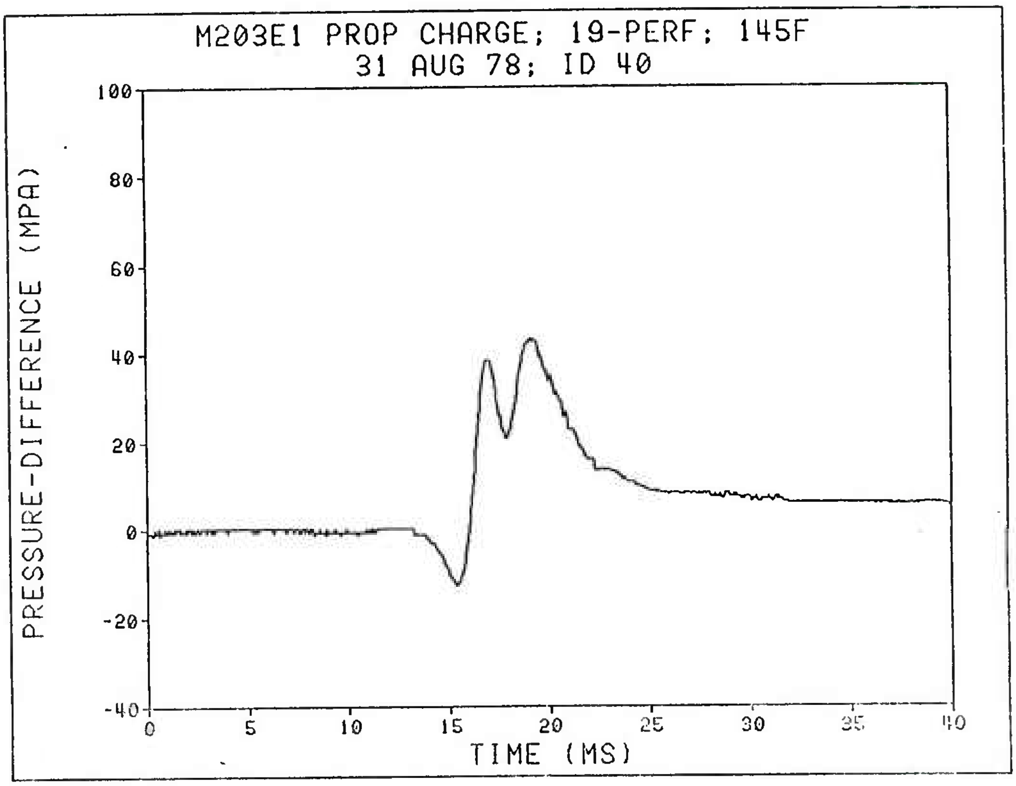
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 40
PRESSURE-DIFFERENCE (MPA)
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0
-20
-40
0
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15
20
25
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35
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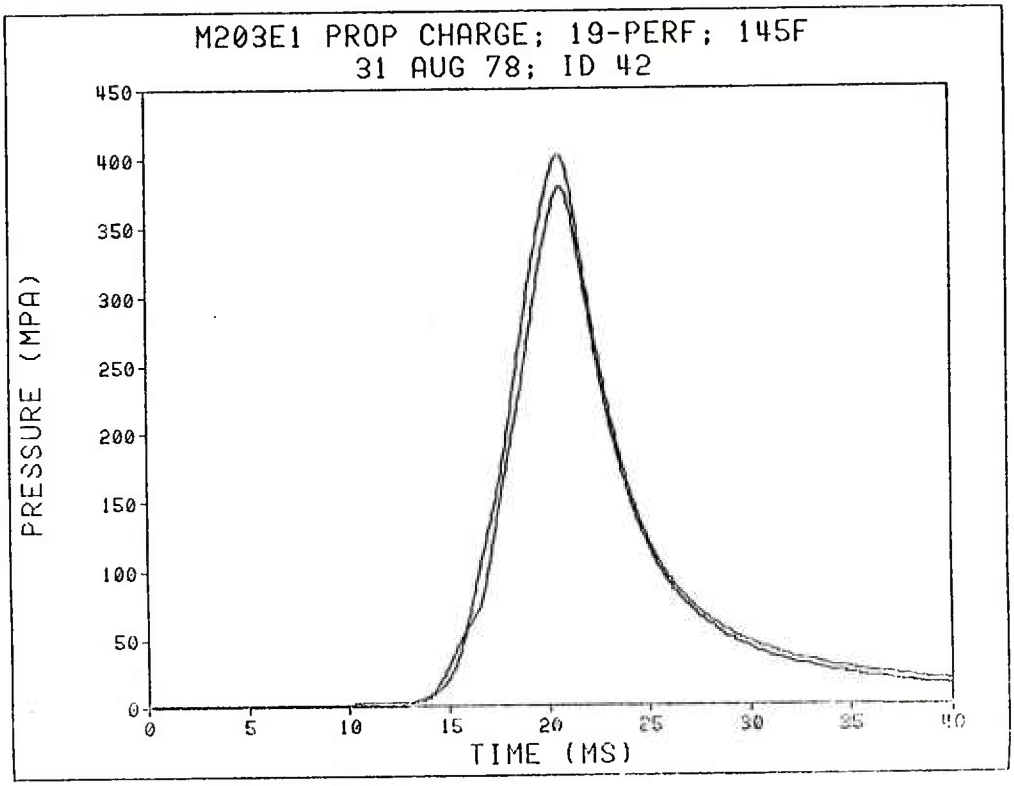
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 42
PRESSURE (MPA)
TIME (MS)
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300
250
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35
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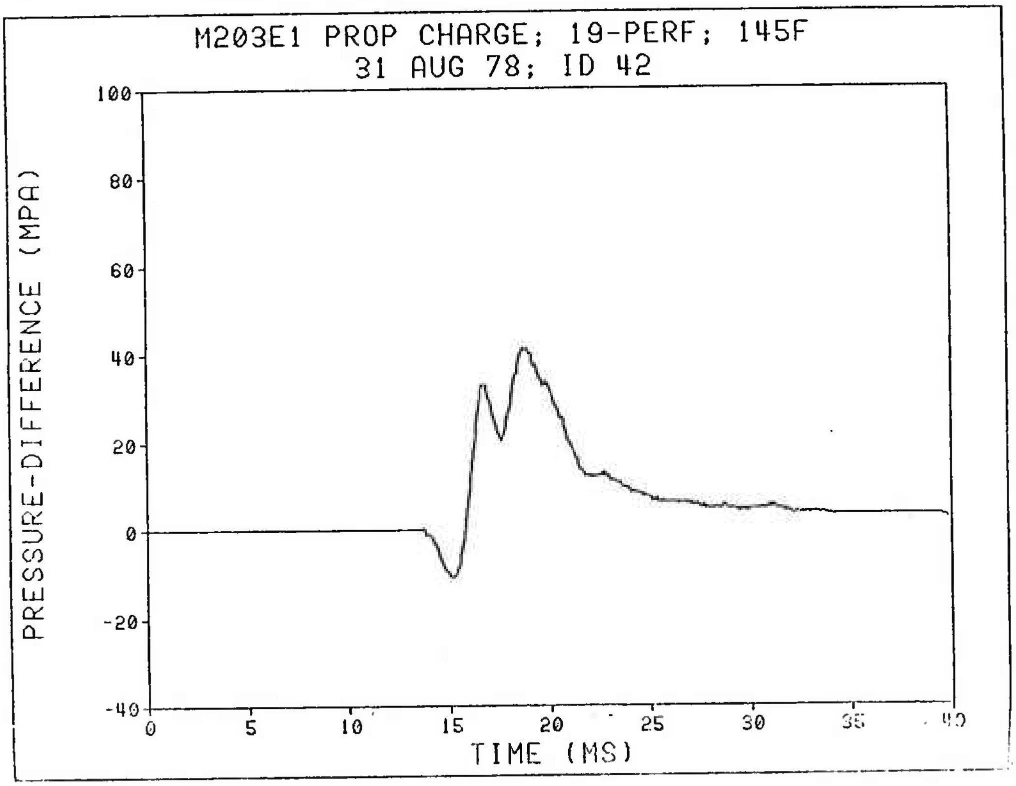
M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 42
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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60
40
20
0
-20
-40
0
5
10
15
20
25
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35
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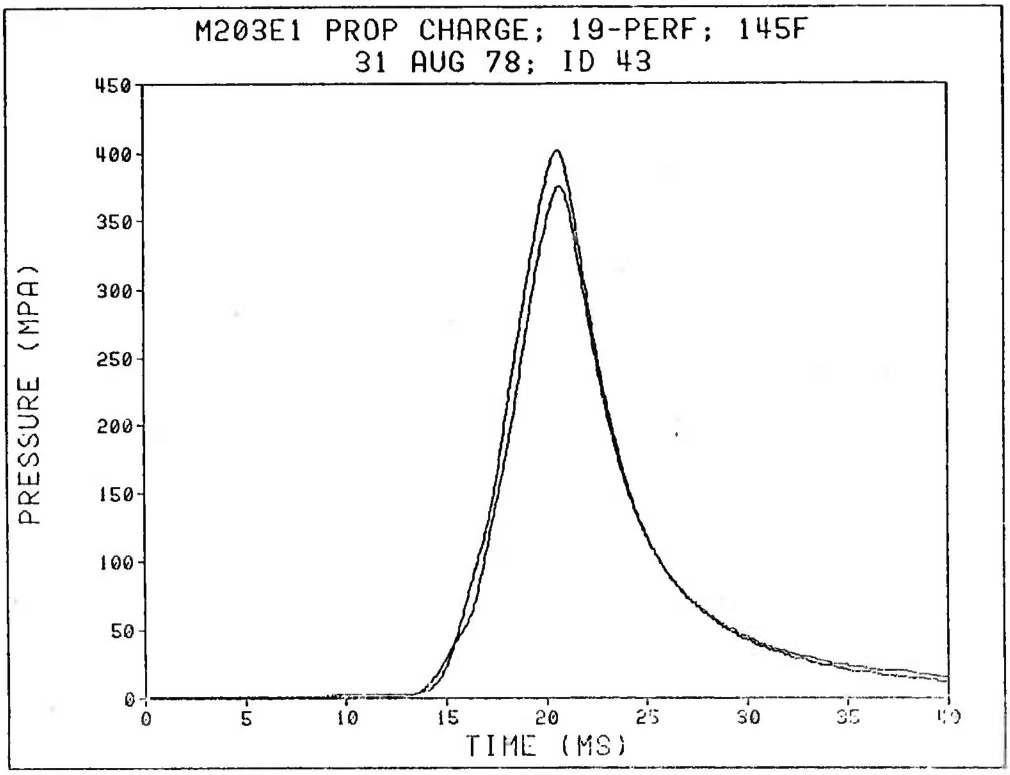
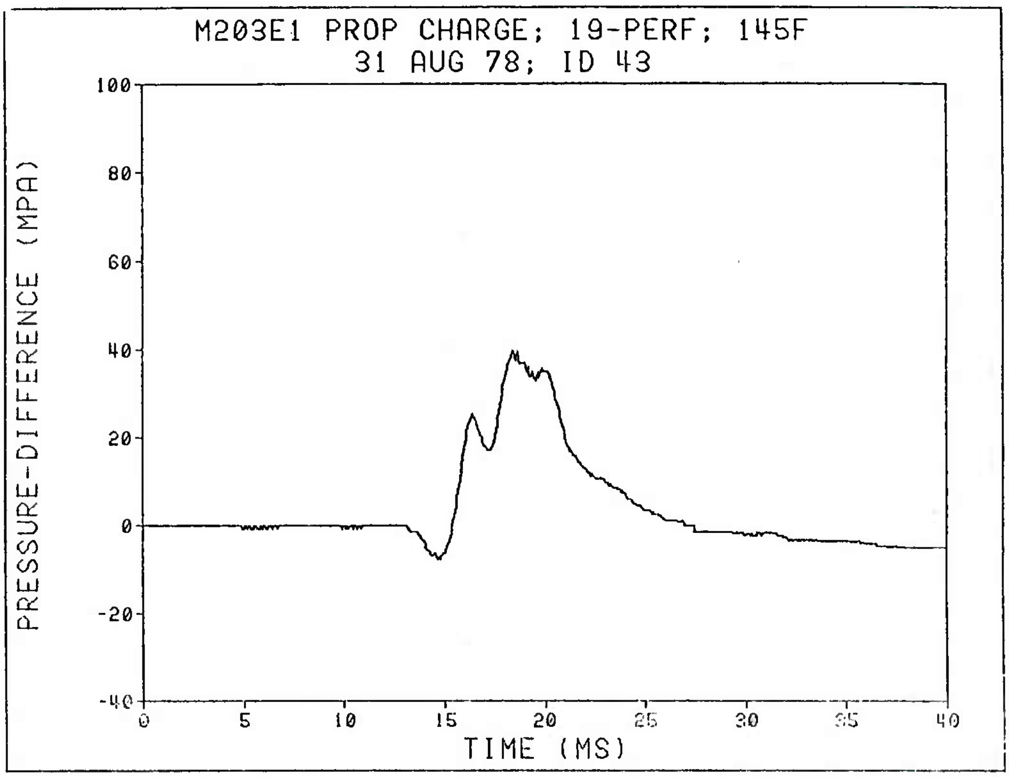
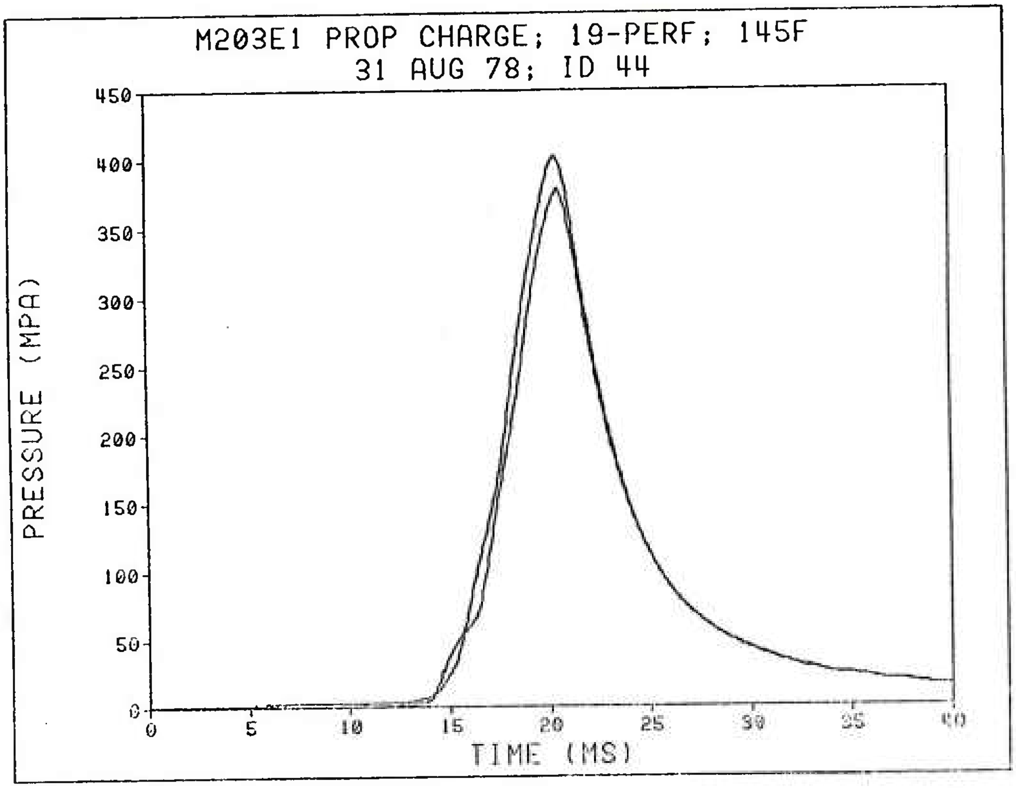

M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 43
PRESSURE (MPA)
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 43
PRESSURE-DIFFERENCE (MPA)
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 44
PRESSURE (MPA)
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200
150
100
50
0
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10
15
20
25
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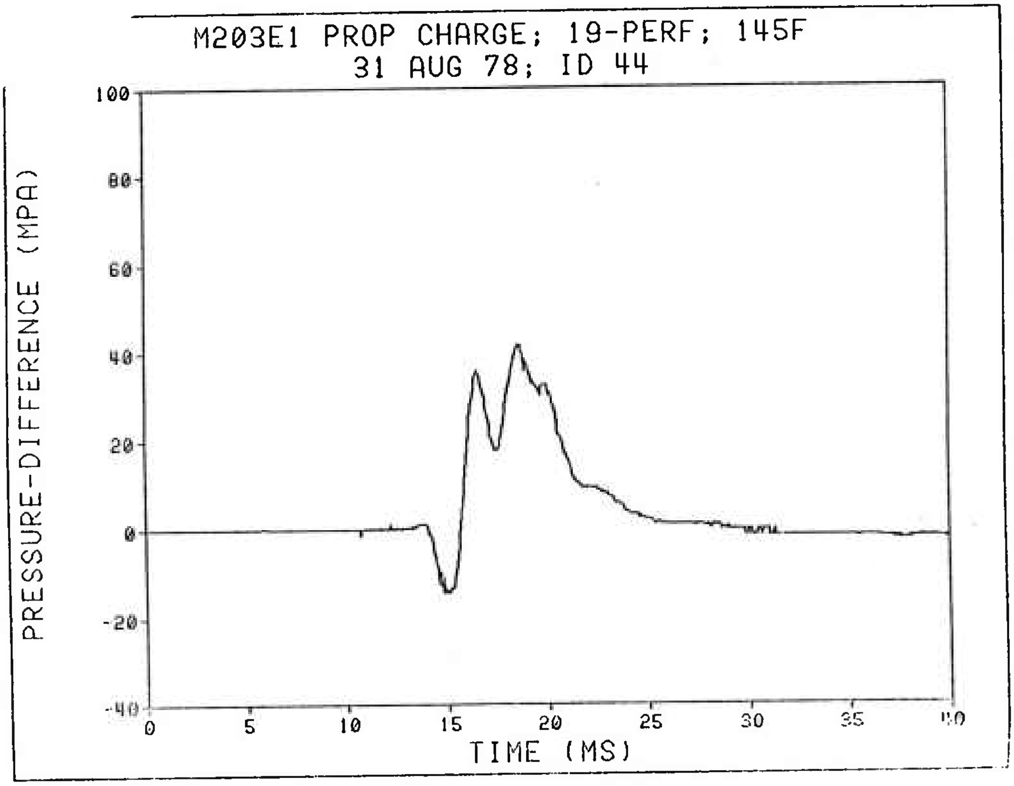
35
40
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 44
PRESSURE-DIFFERENCE (MPA)
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-20
-40
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15
20
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35
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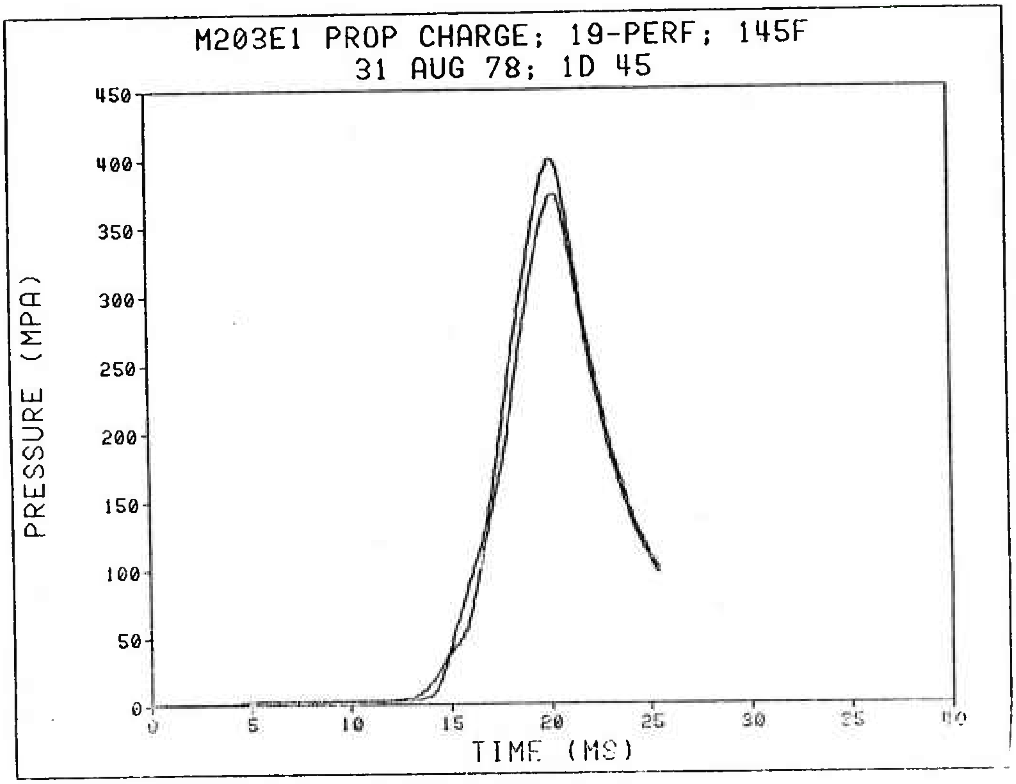
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; 1D 45
PRESSURE (MPA)
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150
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0
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15
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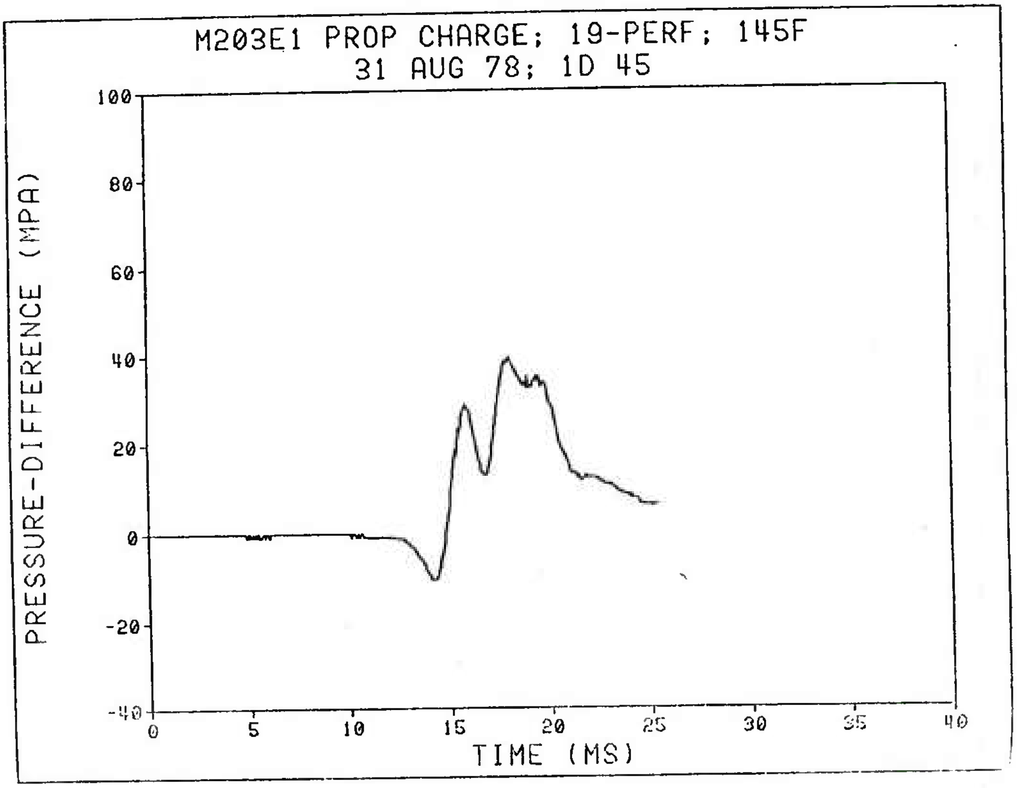
TIME (MS)


M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; 1D 45
PRESSURE-DIFFERENCE (MPA)
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20
0
-20
-40
0
5
10
15
20
25
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35
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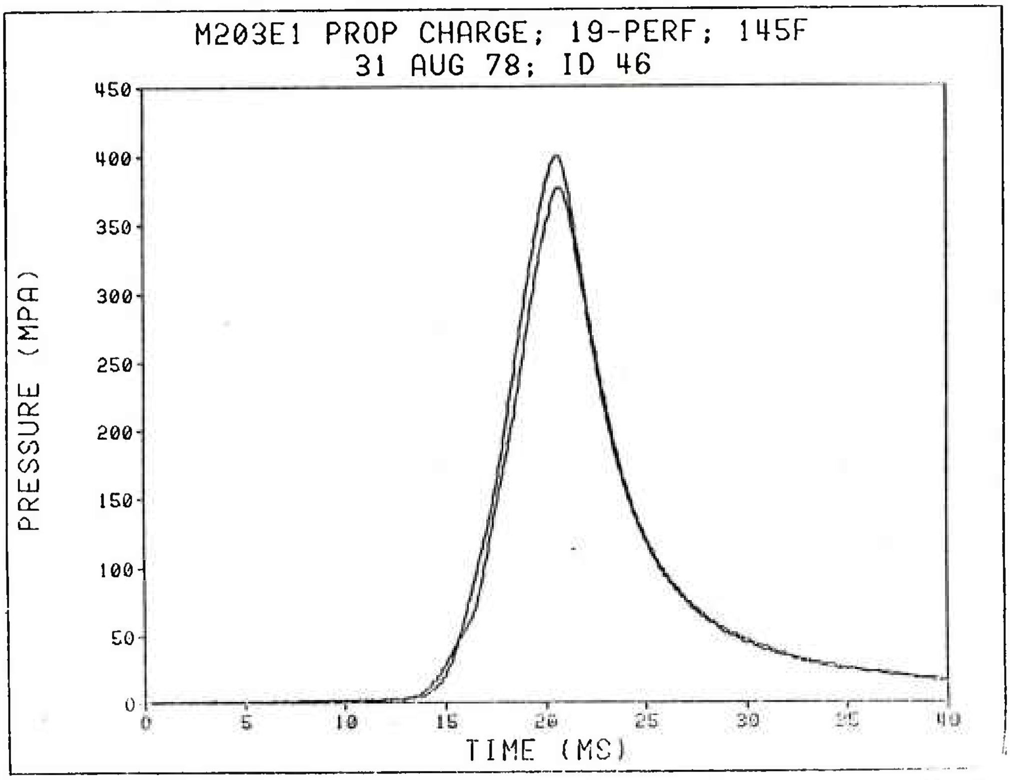
TIME (MS)



M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 46
PRESSURE (MPA)
TIME (MS)
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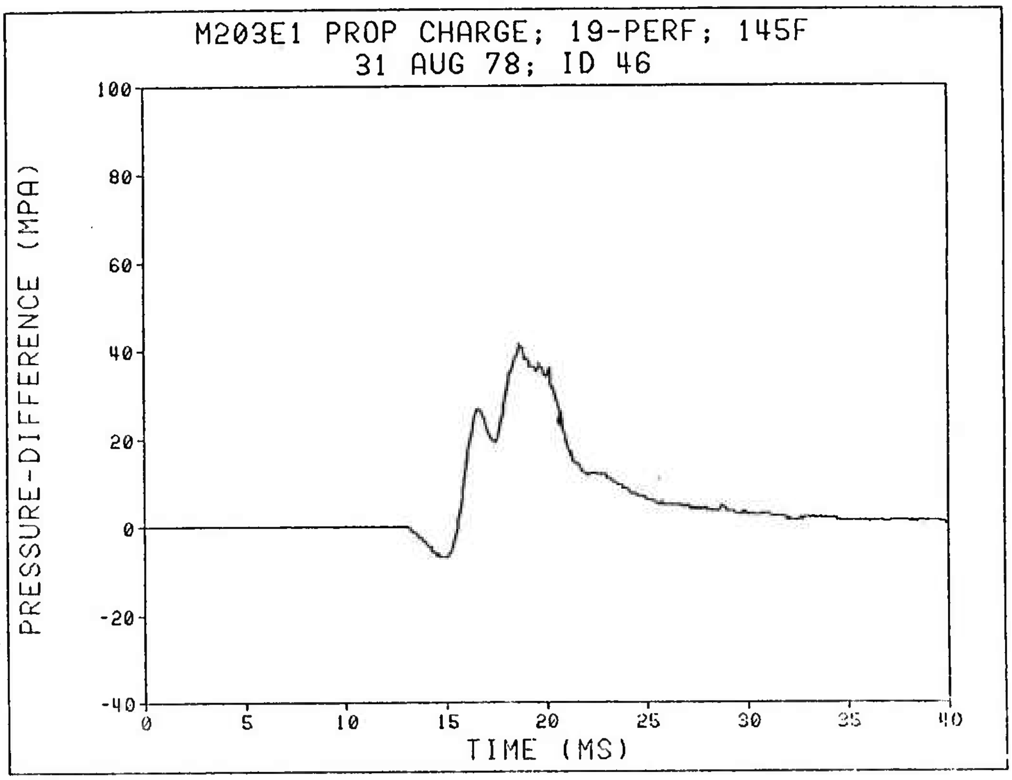

M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 46
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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-20
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20
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60
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10
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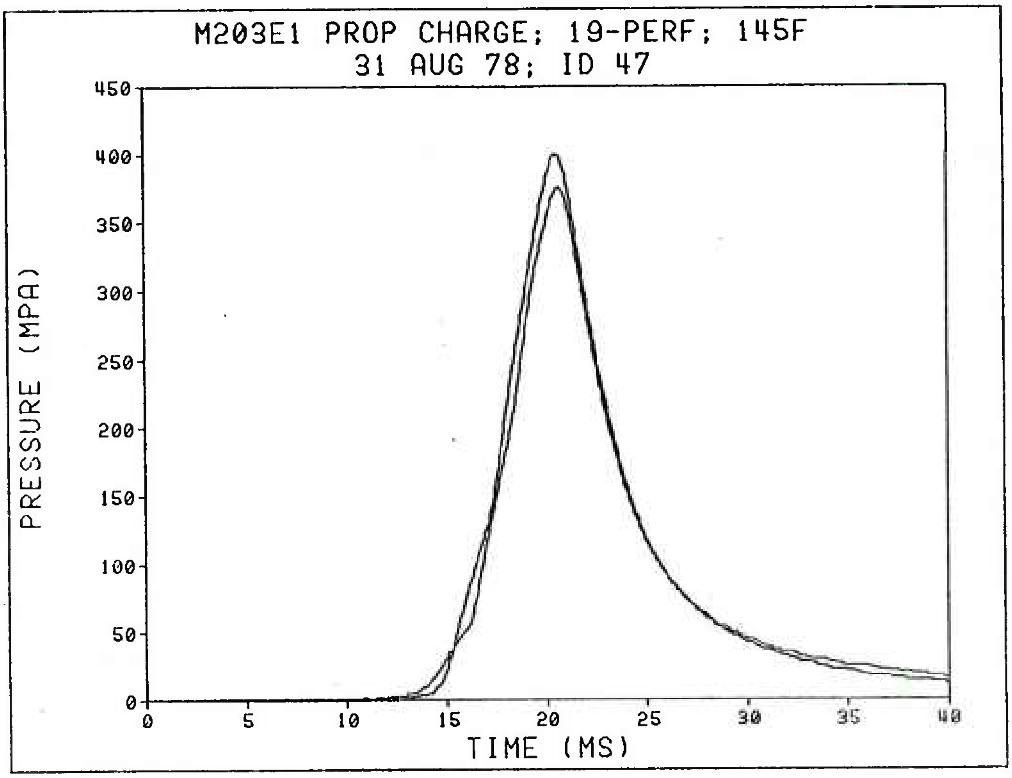
M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 47
PRESSURE (MPA)
TIME (MS)
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400
450
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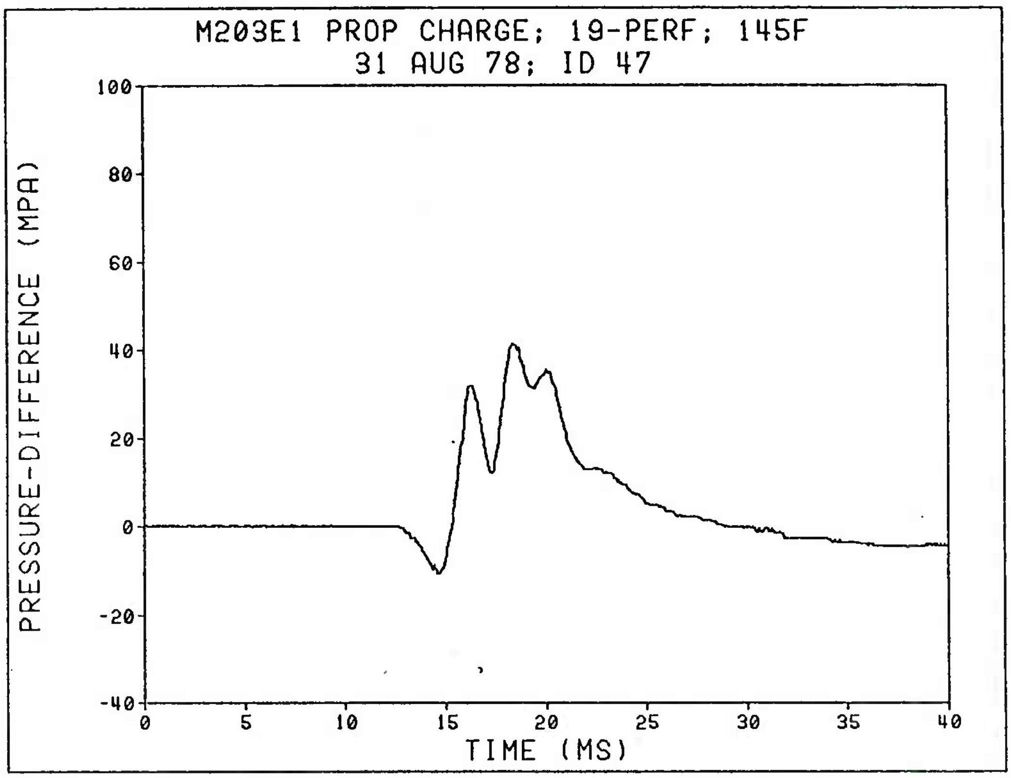
M203E1 PROP CHARGE; 19-PERF; 145F
31 AUG 78; ID 47
PRESSURE-DIFFERENCE (MPA)
TIME (MS)
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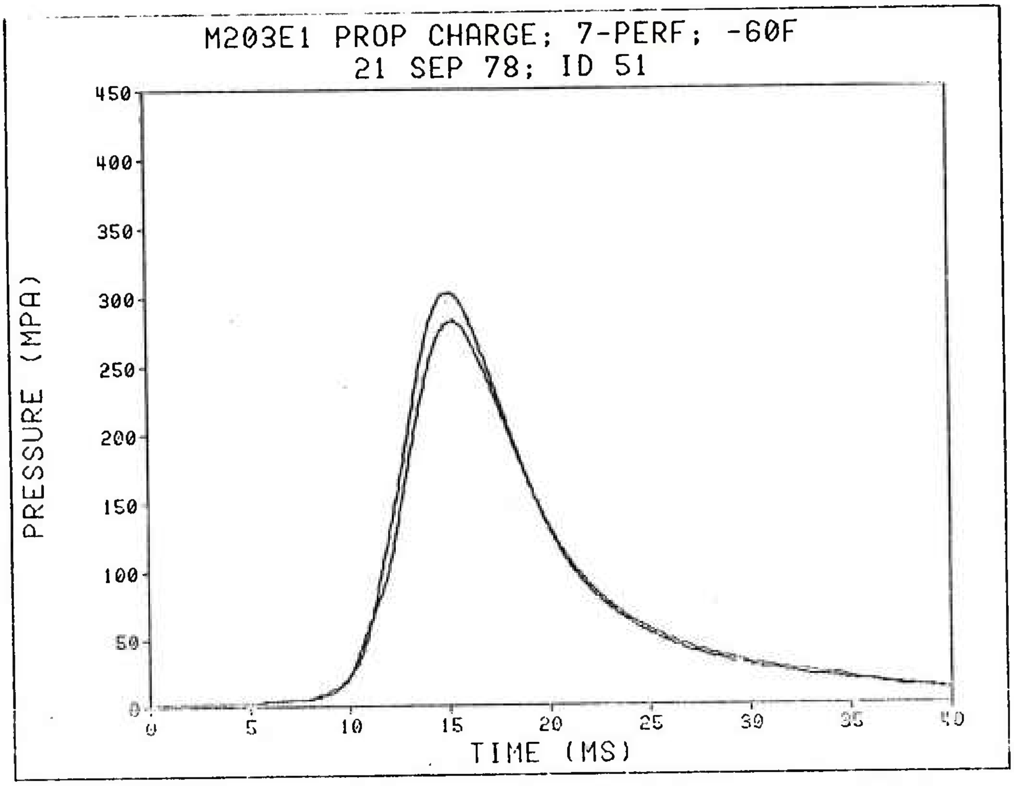
M203E1 PROP CHARGE; 7-PERF; -60F
21 SEP 78; ID 51
PRESSURE (MPA)
450
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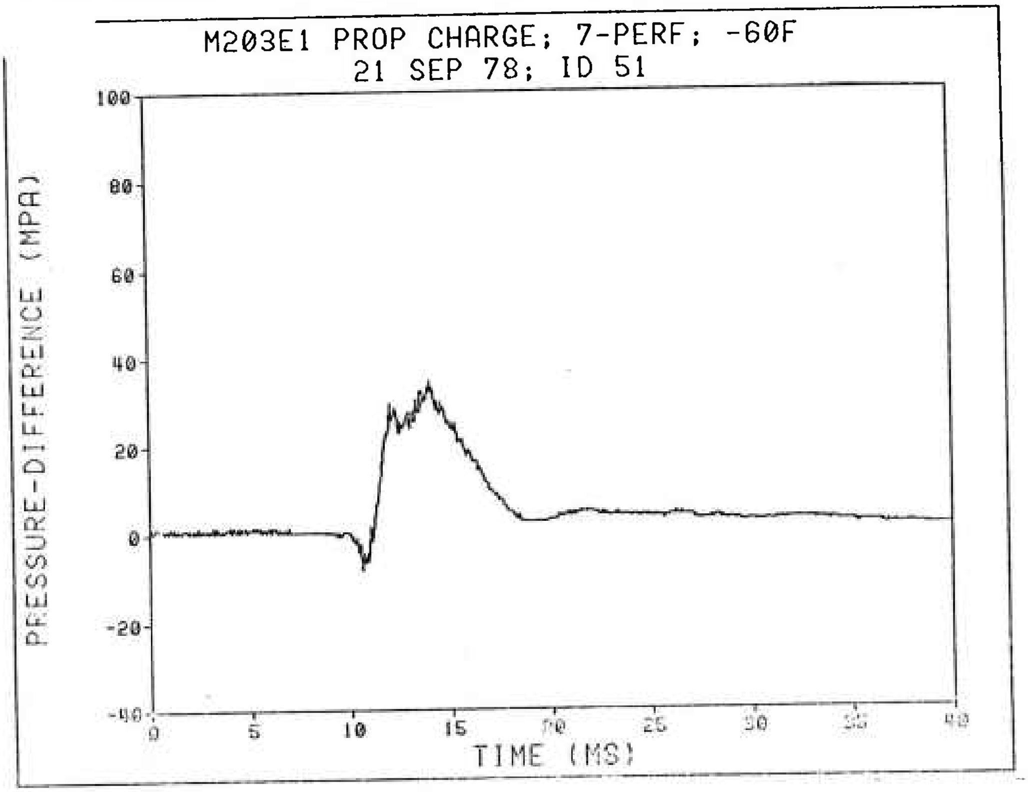
200
150
100
50
0
0
5
10
15
20
25
30
35
40
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; -60F
21 SEP 78; ID 51
PRESSURE-DIFFERENCE (MPA)
100
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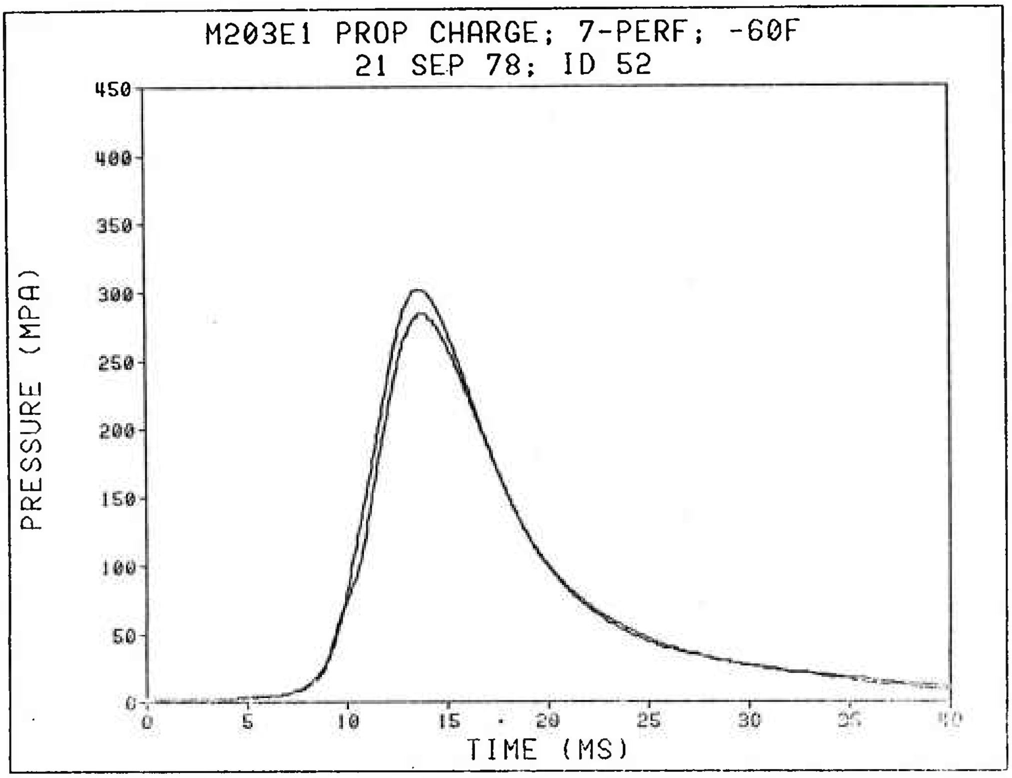
60
40
20
0
-20
-40
0
5
10
15
25
30
40
TIME (MS)


M203E1 PROP CHARGE; 7-PERF; -60F
21 SEP 78; ID 52
PRESSURE (MPA)
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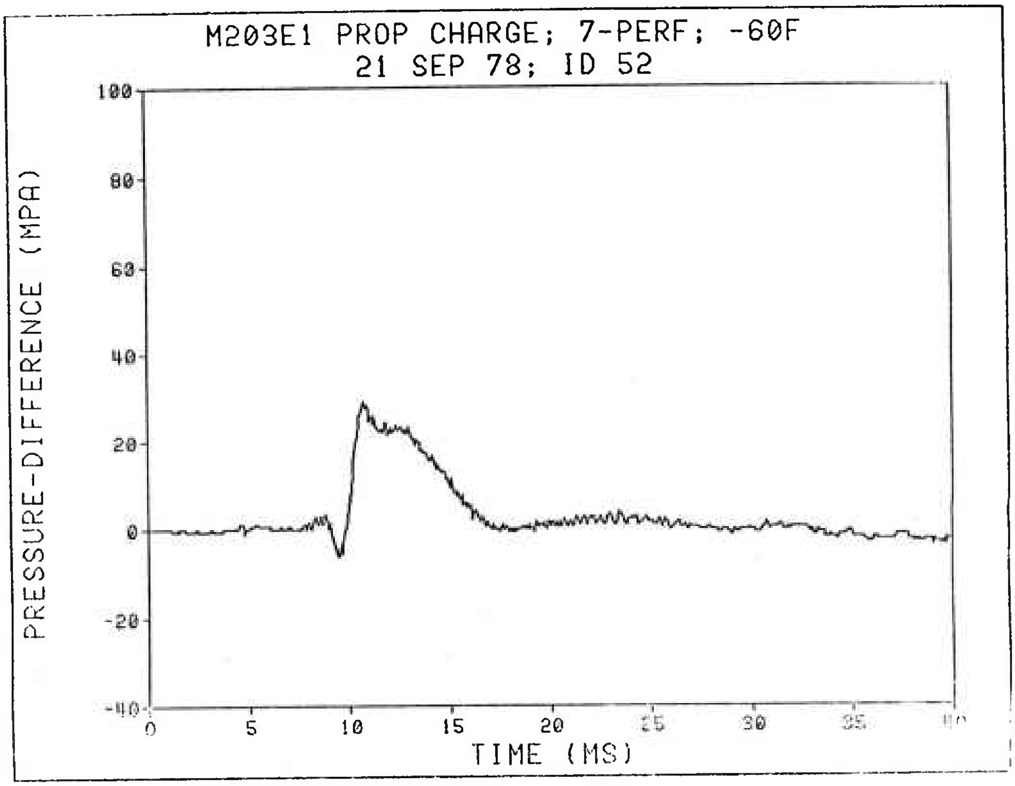
TIME (MS)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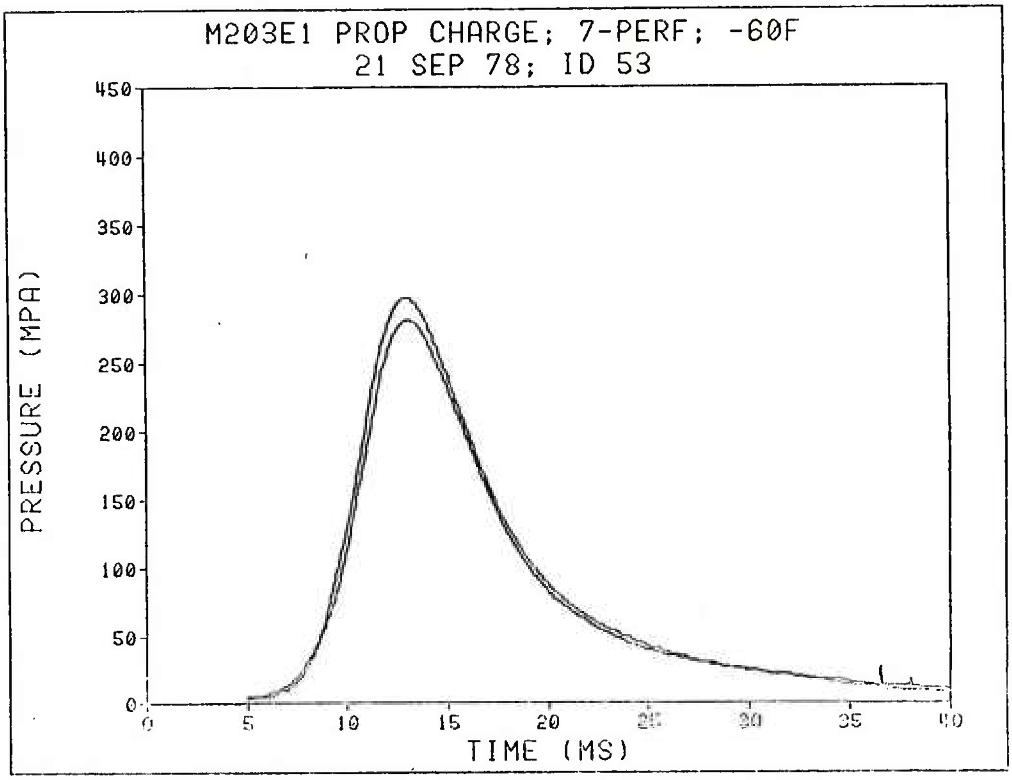
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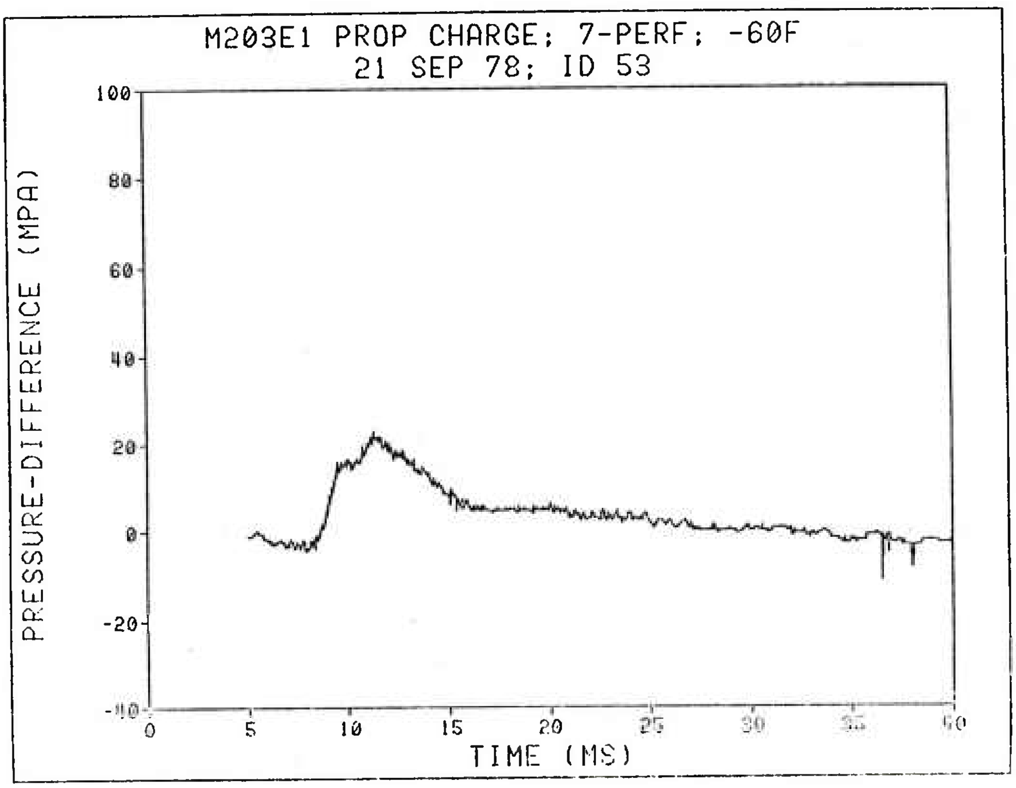
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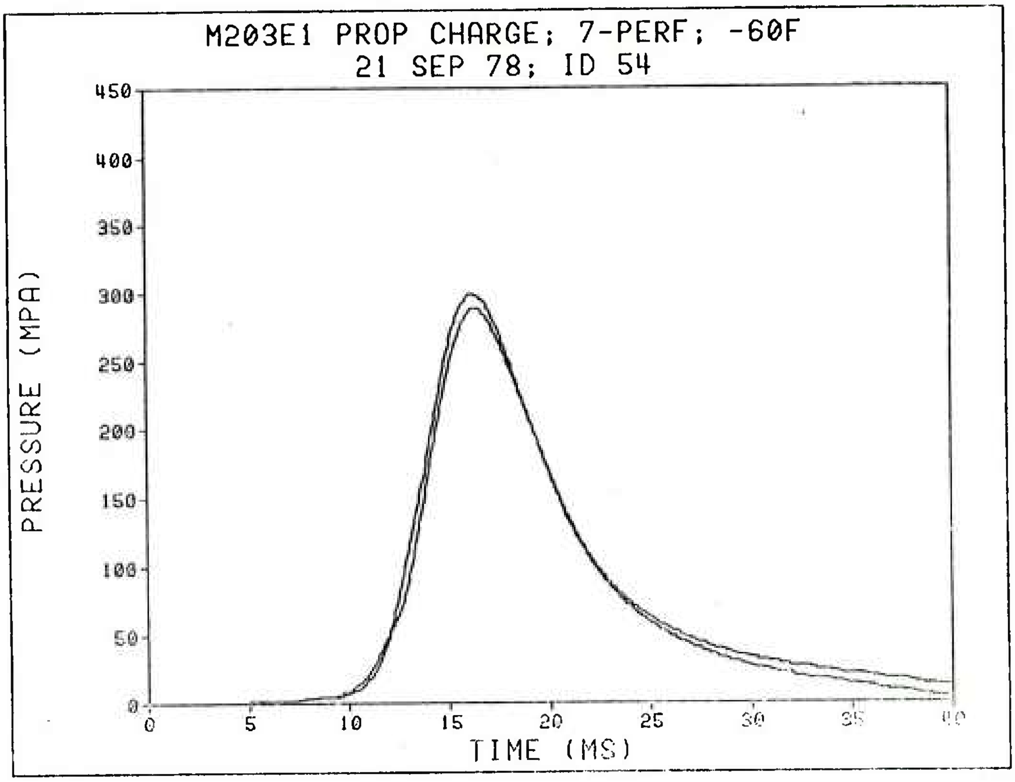
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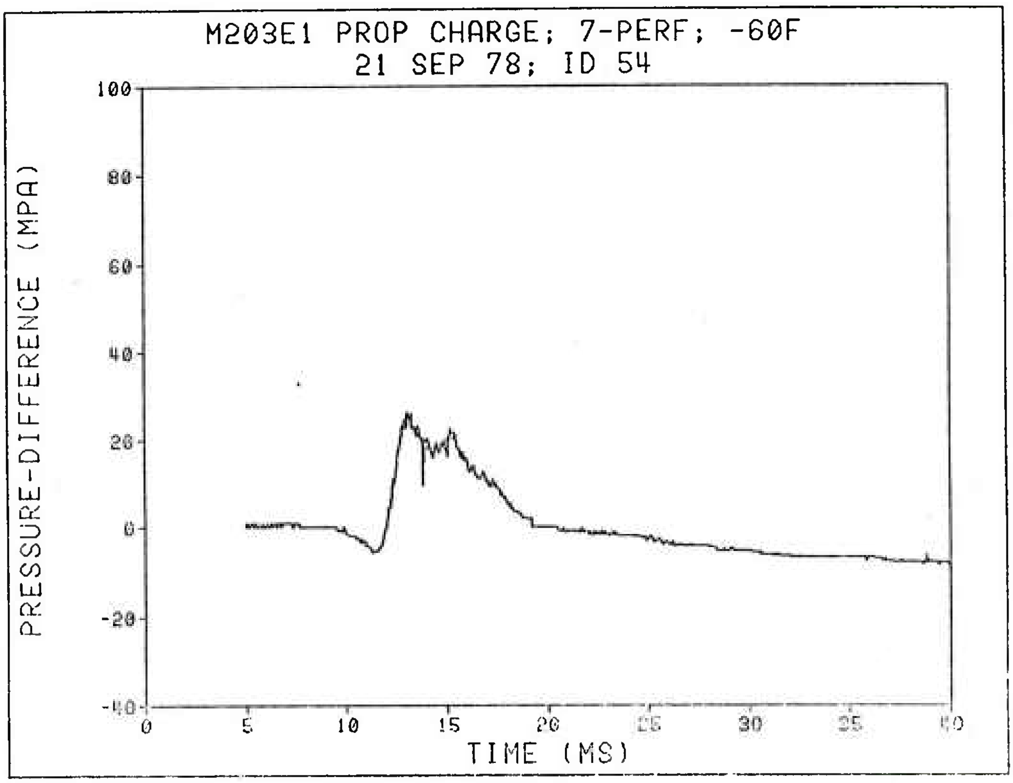
TIME (MS)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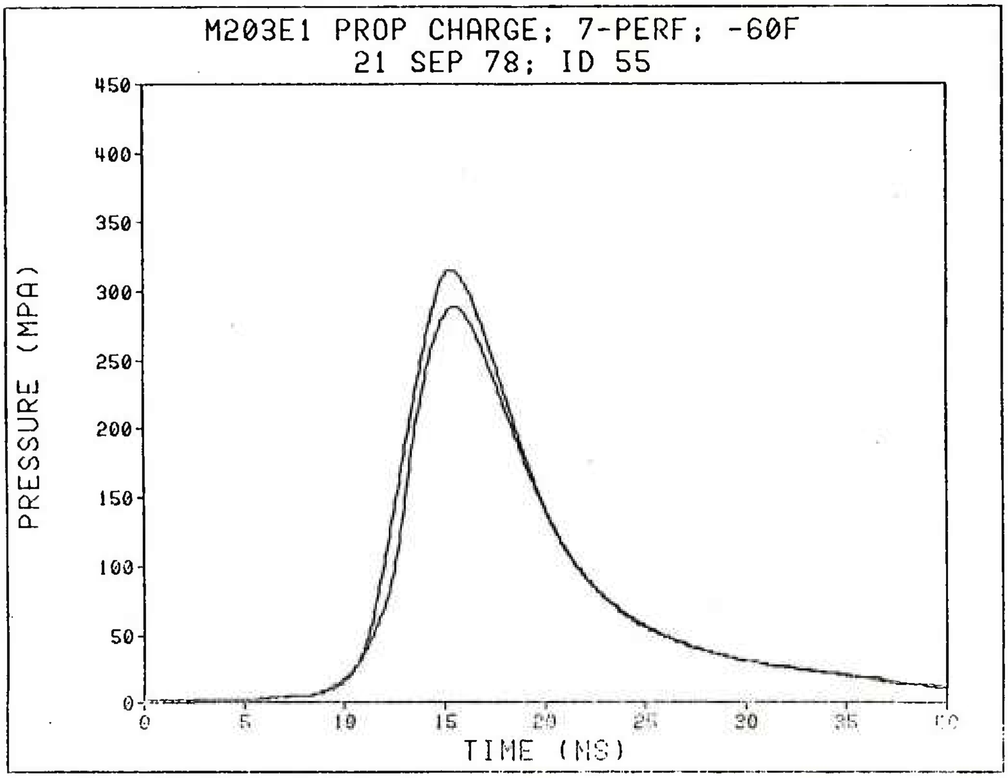
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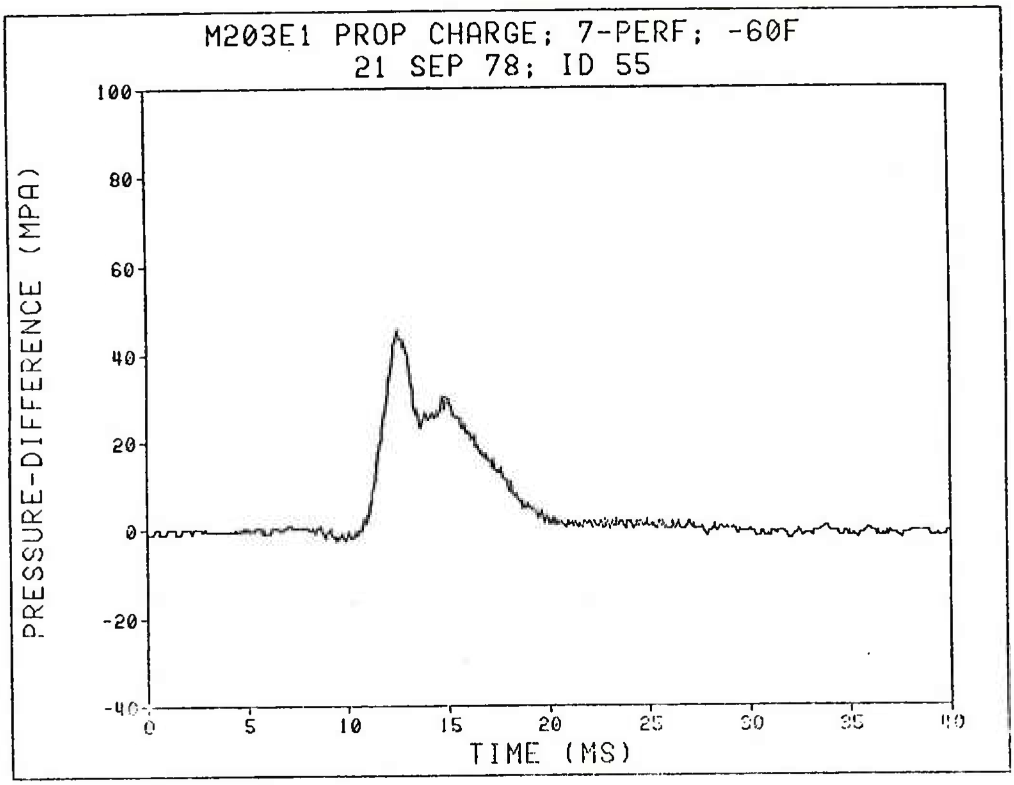
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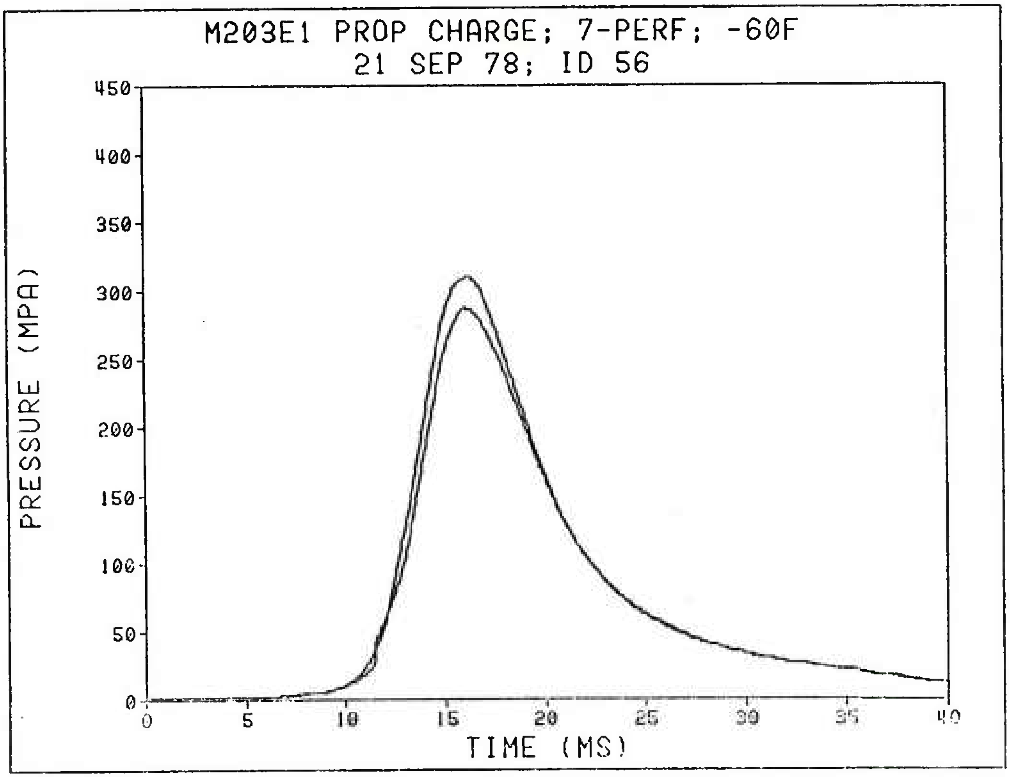
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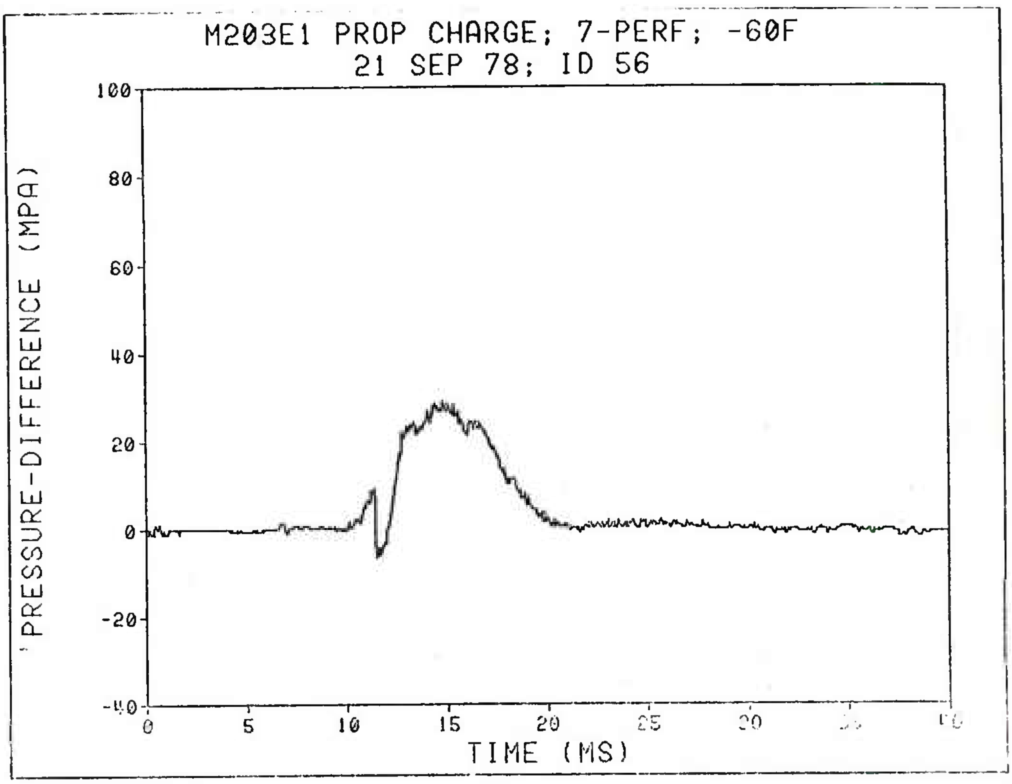
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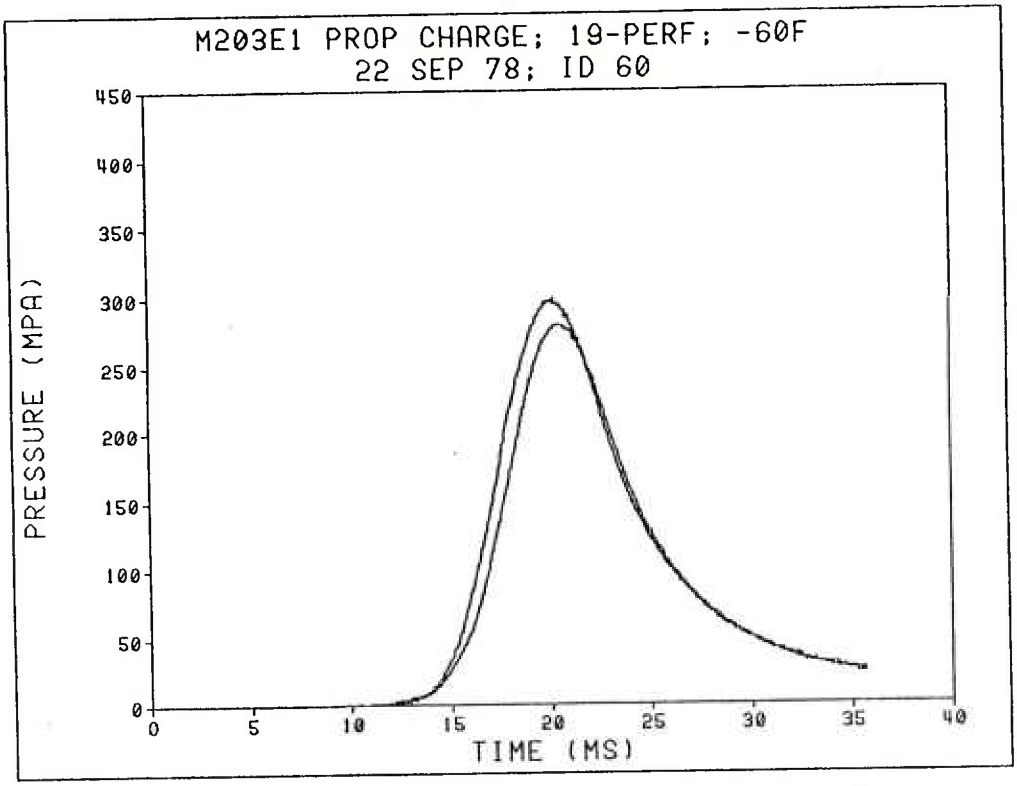
TIME (MS)



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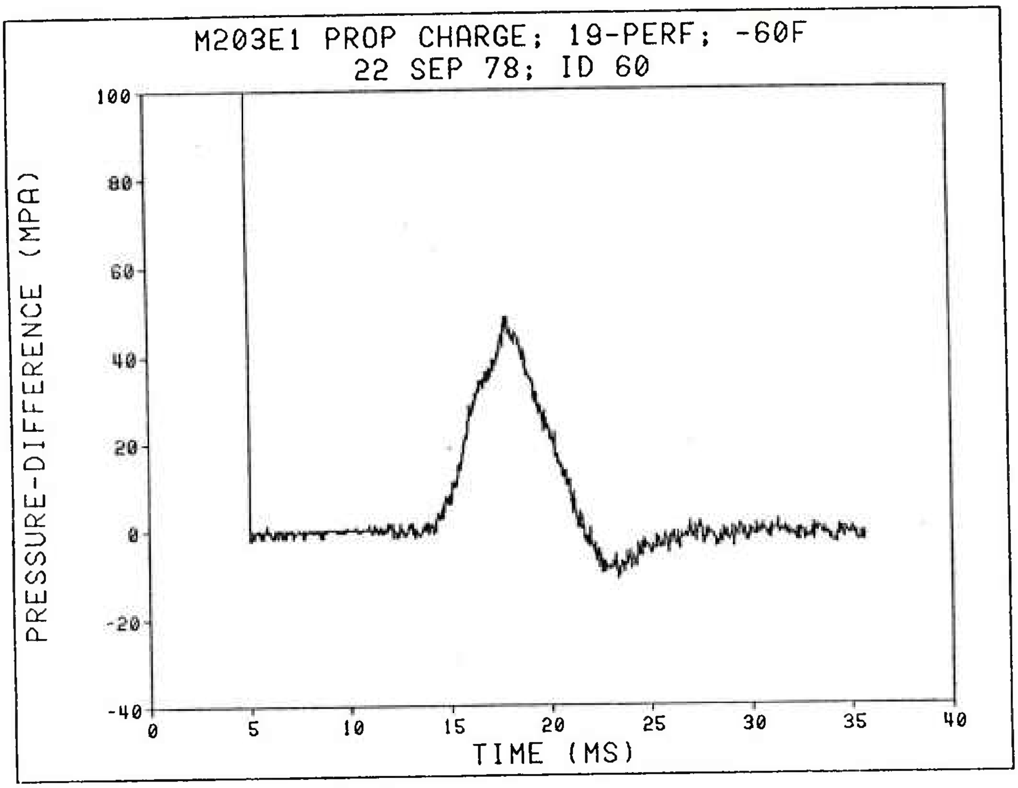
TIME (MS)



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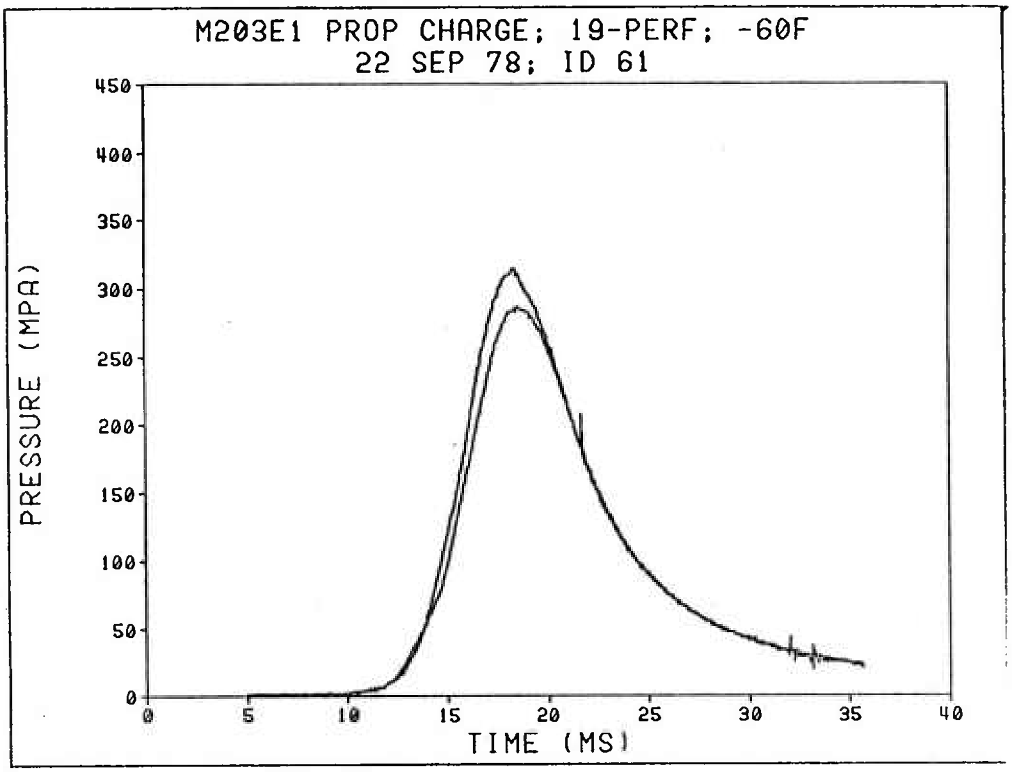
TIME (MS)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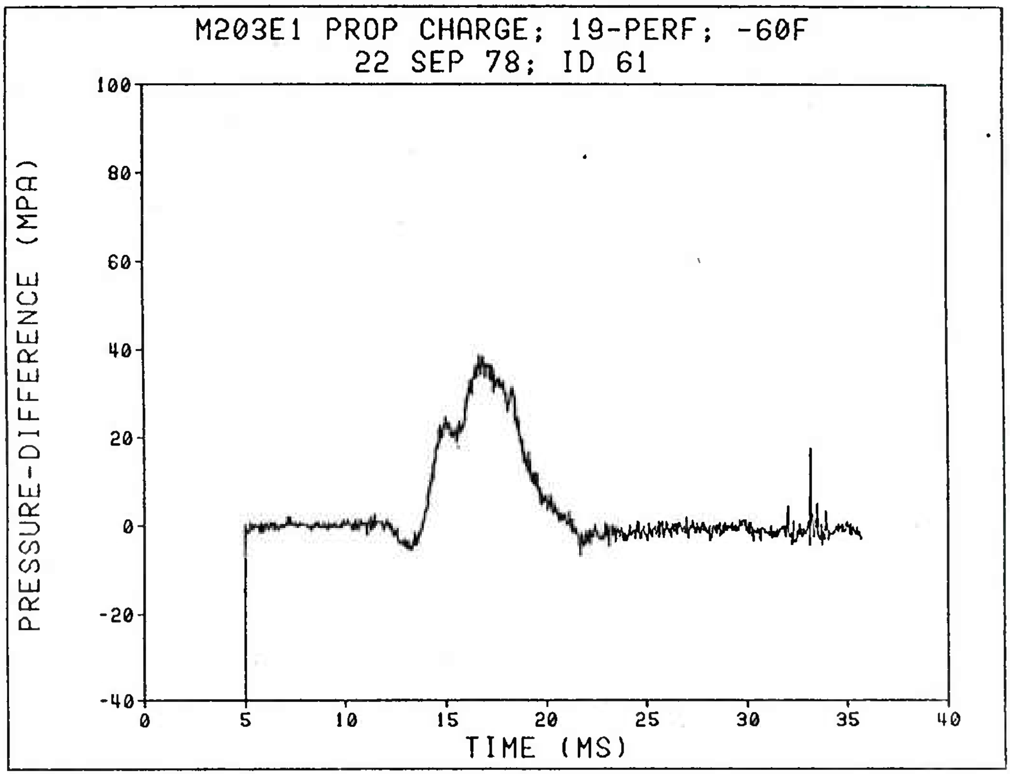
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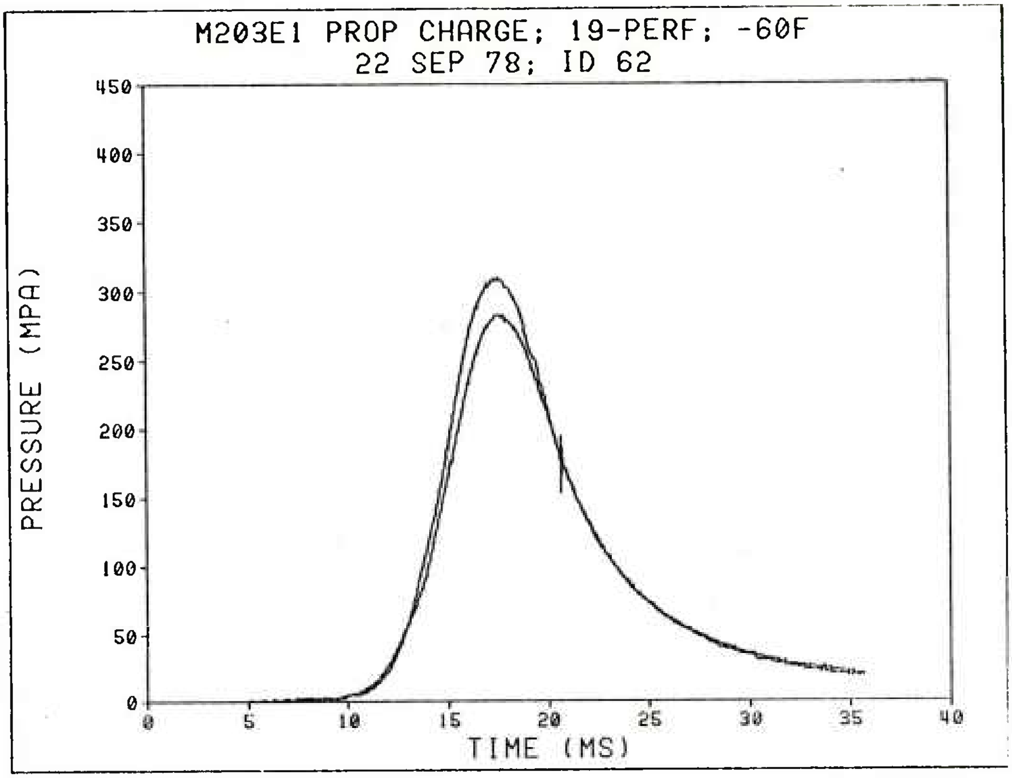
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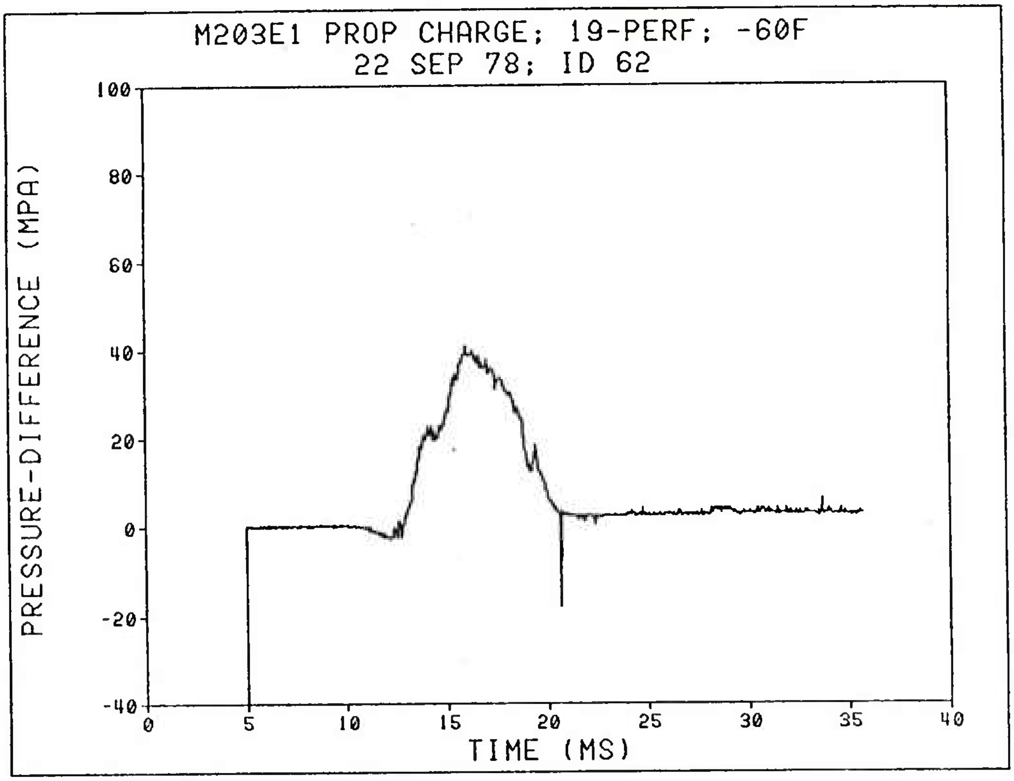
TIME (MS)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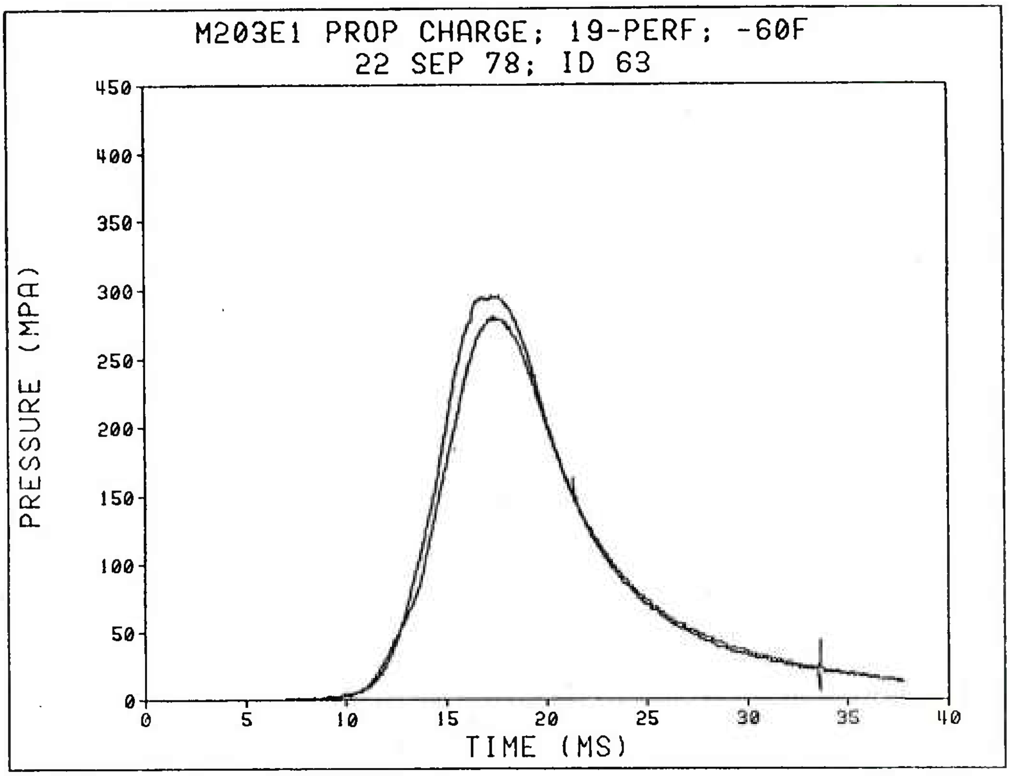
TIME (MS)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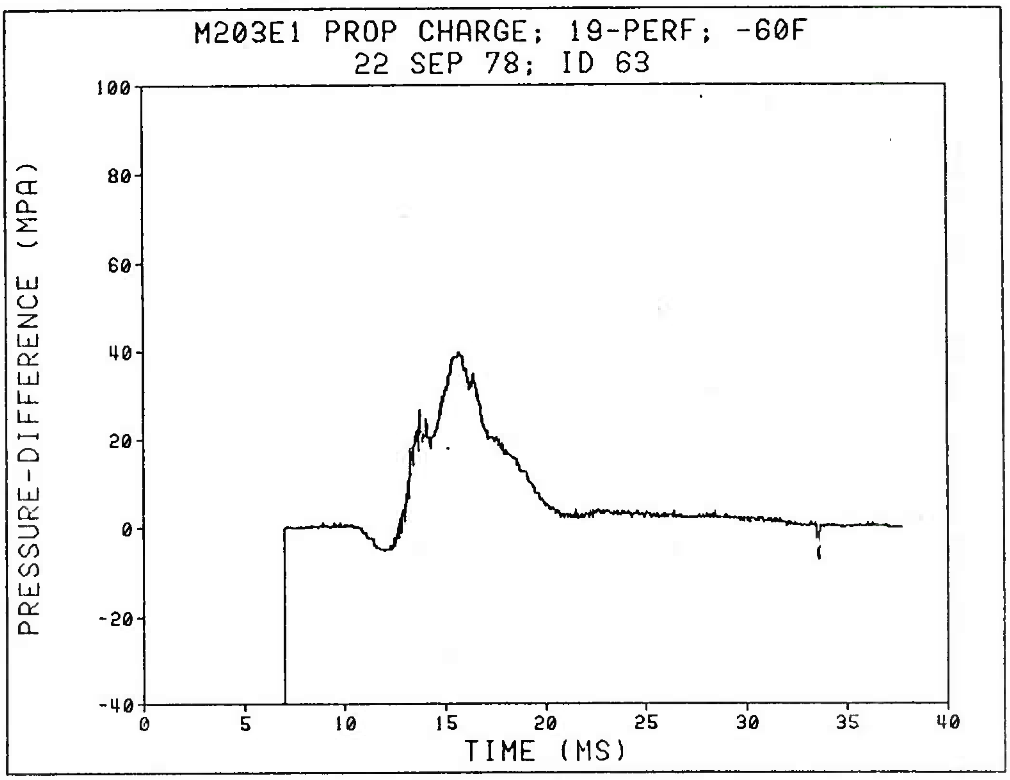
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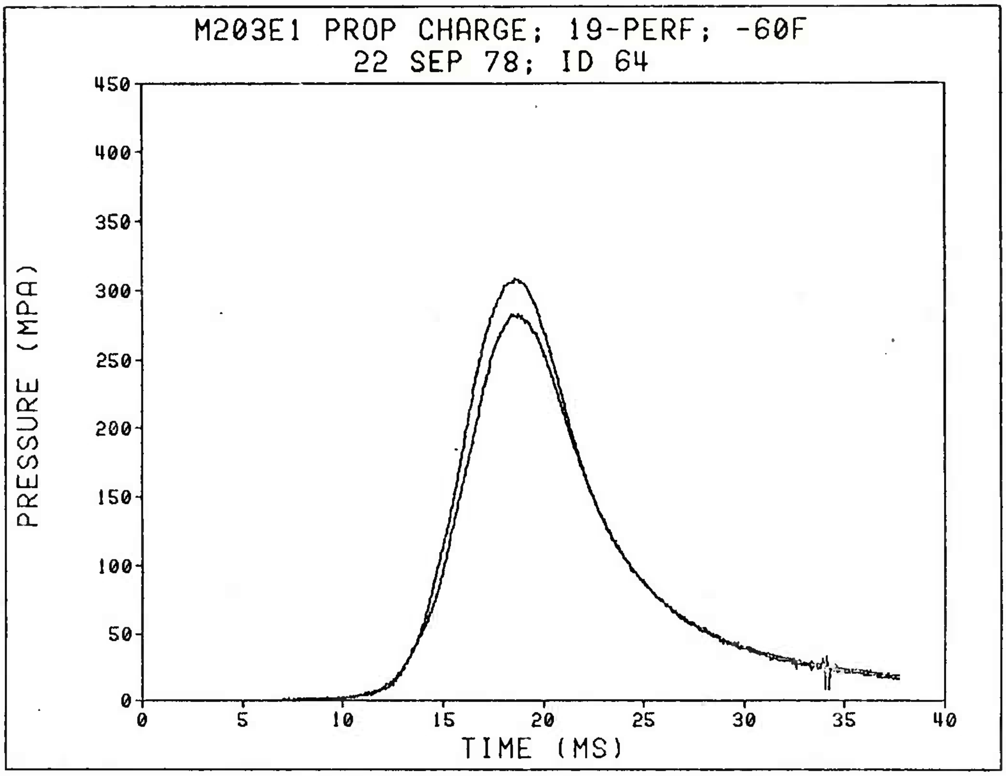
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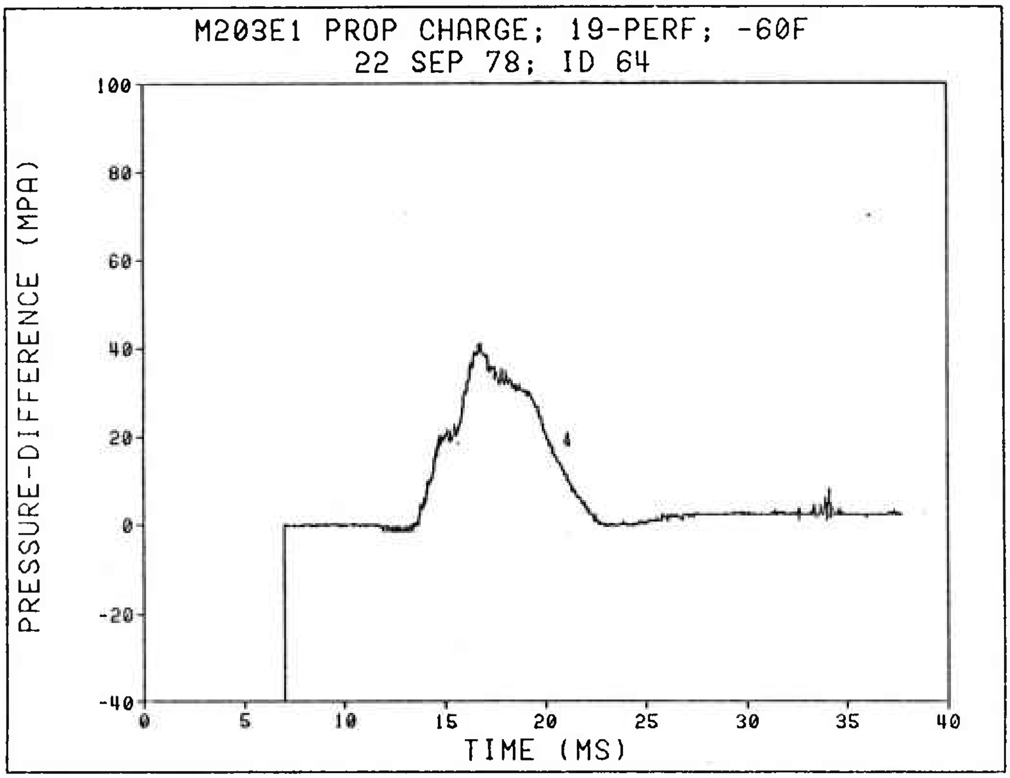
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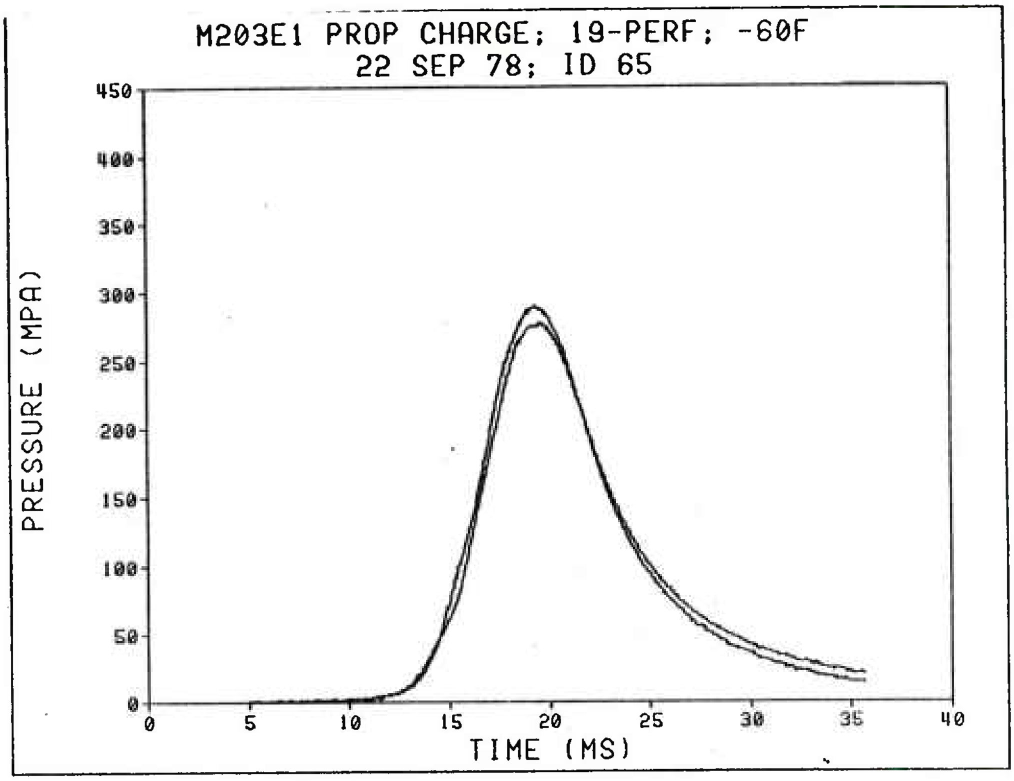
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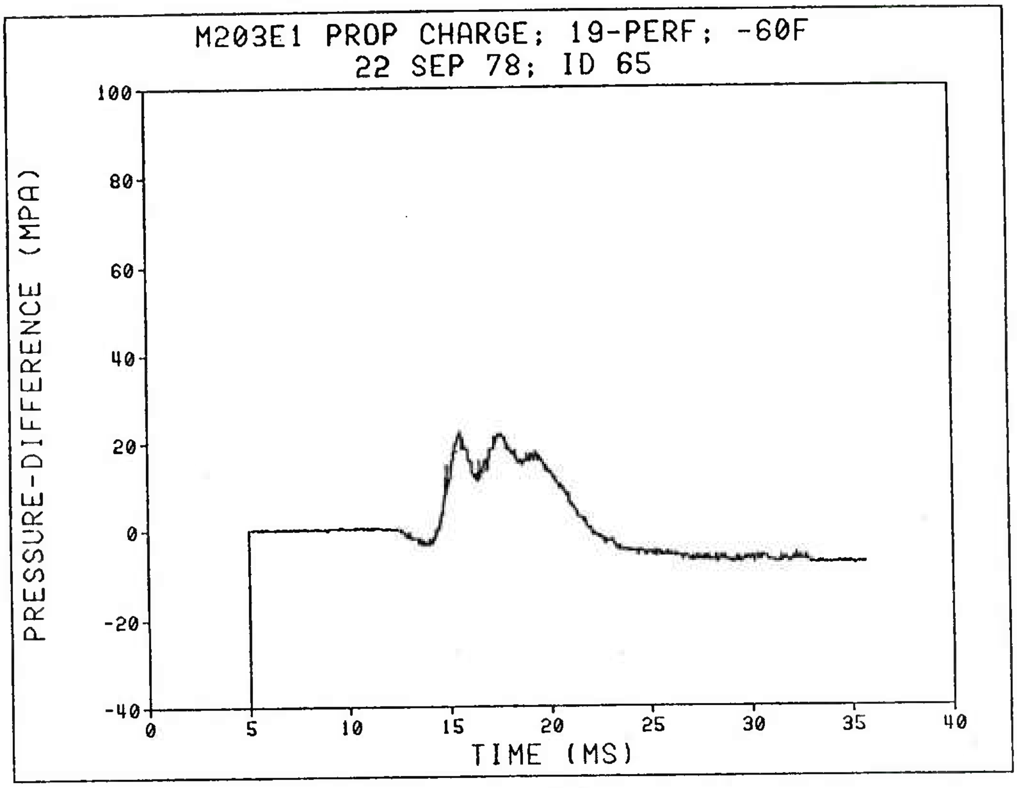
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